Bank risk, bailouts and ambiguity

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BANK RISK, BAILOUTS AND AMBIGUITY

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1

INTRODUCTION

The global banking sector has changed enormously in the last decades: banks have assumed increasingly more diverse roles in the economy. This diversification of bank activities has made daily bank practice very opaque and complex, such that investors, consumers and regulators are hampered in getting correct, complete information while dealing with banks. The rapid innovations in the financial sector have contributed greatly to these informational asymmetries. While banks have found new ways to shed risk and liquify their balance sheets, they became more opaque and correlated in the process. The financial crisis of 2008 and 2009 has made this very clear in a painful way (Brunnermeier, 2009).

Due to this crisis it is now recognized that a large part of bank risk is now systemic instead of idiosyncratic: banks pose a risk to the financial system as a whole. The reform of the regulatory and supervisory framework takes this problem seriously, as both measurement and containment of systemic risk have become paramount. Furthermore, the safety net and resolution mechanisms have to be redesigned to not only cope with Too-Big-to-Fail (as before), but also with Too-Connected- or Too-Many-to-Fail situations.

The financial crisis has also confirmed that, due to the increased opacity of banks, it has become more difficult for regulators to distinguish liquidity from solvency problems. According to Bagehot (1873) it is sensible to provide assistance to a bank in need of temporary funding (liquidity), provided that this bank will have positive charter value in the longer run (solvency). However, many banks that have been assisted during the crisis turned out to be insolvent ex post, even those that were not of systemic importance. Because of their opacity it was not possible to verify asset quality ex ante. As a consequence these insolvent banks had to be bailed out by governments and deposit insurance institutions (such as the US FDIC). These authorities have provided banks with debt guarantees and equity capital, which have been very costly to taxpayers in the United States and Europe alike (Acharya et al., 2009; Panetta et al., 2009).

As other crises (such as the Great Depression in the 1930s or the Savings and Loans crisis in the 1980s) have done before, the recent crisis has prompted a paradigm shift. The world's financial system will change significantly in the near future. At the same time, its regulation and the institutions enforcing it, such as central banks, will have to be redesigned (Cukierman, 2011). The financial safety net, which comprises deposit insurance, the lender of last resort and other safeguards, is part of this regulatory framework. Serious reforms, not in the least politically, are needed to create a safety net that can prevent financial disasters while also preventing imprudent behaviour by financial institutions. This will require going back to the drawing table and combining new insights with old, fundamental concepts.

An important concept, prevalent prior to the crisis and perhaps useful today, is that of constructive ambiguity: central banks would be ambiguous about whether they would provide assistance or not. This was intended to prevent regulatory forbearance, endogeneity of central bank policy and the "gaming" of the safety net. However, since the start of the financial crisis policymakers have not been able to adhere to ambiguity, as they have provided practically unlimited support to the financial system. This does not only concern systemically important institutions (which will always be saved), but also less important banks which, in isolation, should not have been assisted.

The chairmen of the European Central Bank and the United States Federal Reserve have even stated explicitly that they are standing ready to act if banks (or countries, for that matter) are in need of assistance, be it temporary or not. This de facto blanket guarantee provides scope for moral hazard by financial institutions and may prove to be very costly to society if maintained for a long time. Reinstating a framework with ambiguity, built on central bank credibility and reputation, may therefore be more sustainable in the long run.

This dissertation investigates in which way banks created (excessive) systemic risk and, subsequently, analyzes how the financial safety net can affect risk taking. In particular, the first part of this dissertation investigates empirically in which way banks increased their systemic risk. The theoretical analysis in the second part of the dissertation (consisting of three chapters) will be informative for setting up a new system of liquidity and solvency assistance to banks.

Chapter two contributes to the recognition that systematic bank risk and correlation should also be taken into account in measuring systemic risks. It is an investigation into banks' use of credit risk transfer instruments and its effect on individual and systemic risk before the crisis. The two credit risk transfer instruments considered in this study are Credit Default Swaps (CDS) and Collateralized Loan Obligations (CLOs). CDS are derivatives that are used to trade the risk on underlying assets on banks' balance sheets, while CLOs are structured products that remove risks from these balance sheets.

Using two samples of banks respectively trading CDS and issuing CLOs, the systematic risk of banks as perceived by the market is studied. After their first use of either risk transfer method, the share price beta of these banks increases significantly. This suggests the market anticipated the risks arising from these methods, long before the crisis. What is more, this increase in risk lasts until the end of the sample and the effect from CLOs is larger than that from CDS.

This beta effect can be separated into a volatility and a market correlation component. This exercise reveals that volatility decreases while correlation increases, which means that the increase in the beta is solely due to an increase in banks' correlations. Thus, while banks may have shed their individual credit risk, they have increased their importance for the financial system. This creates a challenge for financial regulation, which has typically focused on individual institutions. As has been stressed in recent debates on new regulation, measuring and accounting for systemic risk will become a central part of the new regulatory framework.

The second part of this dissertation, which contains three different theoretical analyses, deals with reforming the regulatory framework. It focuses on crisis management of individual banks in distress, and thus on the interaction between a bank and a regulator in times of crisis. This interaction is modeled by employing noncooperative game theory. While this modeling feature is shared by all three models, they also differ in several respects. The following table delineates the differences and similarities between the models in the respective chapters.

Table 1.1: Overview of model features

	Chapter 3	*Chapter 4*	*Chapter 5*
Players	Bank Central Bank Fiscal Authority	Bank Central Bank	Bank Central Bank
Time structure	Static	Dynamic	Dynamic
Uncertainty	Asset risk		Central Bank mandate
Bank choices	Liquidity Monitoring	Liquidity Capital	Liquidity
Ambiguity	No	Yes	Yes

In all three models there is a bank that chooses its liquidity buffer to cope with idiosyncratic liquidity risk. Additionally, the bank can always turn to the central bank to ask for liquidity assistance. In chapter three this form of safety net is complemented with a fiscal authority, i.e. the ministry of finance, that can provide solvency assistance. Therefore, this model also contains uncertainty about solvency or asset risk, as the bank's asset quality is not known. Chapters four and five then focus on the concept of constructive ambiguity, which is not present in chapter three. To clarify the analysis, these models constrain attention to the game between bank and central bank. In addition, the game in chapters four and five is dynamic, instead of static, to capture banker's myopia. Finally, the feature that distinguishes chapters four and five from each other is regulatory uncertainty. This means that the central bank's mandate is not known, which provides an explicit foundation for constructive ambiguity.

Chapter three examines in a theoretical manner how illiquidity and insolvency resolution interact and affect banks' incentives. During the recent financial crisis, central banks have provided liquidity and governments have set up rescue programmes to restore confidence and stability, often against the Lender of Last Resort principle advocated by Bagehot. The chapter analyzes Bagehot's principle in a stylized model of to assess the effect of liquidity assistance and bailouts on individual bank risk taking.

The model features a systemic bank suffering from idiosyncratic liquidity shocks that cannot be resolved through the interbank market; we assume a crisis situation. Furthermore, there is only imperfect supervisory information on the bank's solvency. Without any form of safety net in place, the bank keeps too much liquidity and monitors too little compared to the social optimum. A central bank can alleviate liquidity problems, but induces moral hazard. Therefore, a fiscal authority that is able to provide solvency assistance is introduced. This assistance, also known as a bailout, can take place by injecting capital at a fixed return (debt) or by claiming a part of bank value (equity). Debt assistance decreases moral hazard and increases productive investment, but has limited potential to alleviate solvency problems. Equity assistance can alleviate all liquidity and solvency problems; it also decreases moral hazard and increases investment. Thus, both manners of solvency assistance provide the right incentives to the bank, while equity assistance can solve a broader range of problems.

The fourth chapter of this dissertation examines a central bank's ability to follow a constructive ambiguity policy in providing liquidity assistance to an individual bank. This means that the central bank will not announce the conditions for liquidity assistance ex ante; instead, it follows a mixed strategy. This ambiguity can dampen bailout expectations that have led banks to behave imprudently, holding too little capital and relying too much on short term funding to finance long term investments. Regulatory forbearance can be mitigated by allowing the central bank to follow an ambiguous liquidity assistance policy.

This constructive ambiguity policy is investigated using a dynamic model of the game between a bank and a regulator, i.e. the central bank/financial supervisor. The bank chooses capital and liquidity ratios, while the institution providing liquidity assistance can commit only to a mixed strategy in equilibrium. The reason behind this is that never assisting the bank is too costly and therefore not credible, while always providing liquidity causes moral hazard. In equilibrium, the bank chooses above minimum capital and liquidity, unless either capital costs or the opportunity cost of liquidity are too high. Additionally, the probability of liquidity assistance is higher for a regulator who is more concerned about bank failure, and when the penalty for the bank is higher; this suggests that forbearance is not entirely eliminated by adhering to constructive ambiguity.

One important assumption has to be satisfied for the constructive ambiguity equilibrium to hold: the central bank must have sufficient credibility to adhere to this strategy ex ante. This is quite a strong assumption, which deserves more investigation; this is the topic of the final chapter.

The fifth and final chapter of this dissertation focuses on the notion that recent actions by central banks in Europe and the US may lead banks to expect that central banks will be lenient in the future. Will this expectation be justified? This question can be answered by using the concept of regulatory ambiguity: the exact objective or preference of the central bank is not public knowledge. This uncertainty can serve as the basis for a constructive ambiguity strategy.

In the model there can be two types of central banks: a Hawk, which is tough, and a Dove, which is lenient. There are two players: a bank and a central bank. The central bank knows which type it is, but the bank does not. It can, however, infer this by observing the regulator's actions and will update its belief accordingly. The central bank is able to build a reputation for being a Hawk if the uncertainty about its nature is high enough. As a result it can credibly adhere to a constructive ambiguity strategy, which will lead the bank to choose higher liquidity reserves in equilibrium. Furthermore, increasing bank capital and penalty rates make it easier to build a reputation, while bailouts by the fiscal government make it more difficult. In the end, by not disclosing its true preference the central bank is able to follow a policy of constructive ambiguity.

The results in this dissertation have implications for the reform of financial regulation and the safety net. By becoming more correlated banks have made themselves systemic, which meant they could not fail without severely damaging the system. We need a new regulatory and supervisory framework that properly takes into account idiosyncratic and systemic risks. In this framework central banks will assume the role of supervisor, but also that of the Lender of Last Resort. This will have to be complemented with a properly designed resolution mechanism, such that governments can assist banks at a suitable penalty. Furthermore, to prevent imprudent behaviour by financial institutions central banks can resort to a policy of constructive ambiguity. A necessary prerequisite, however, is that they have a good reputation that lends credibility to this policy.

2

CREDIT RISK TRANSFER ACTIVITIES AND SYSTEMIC RISK: HOW BANKS BECAME LESS RISKY INDIVIDUALLY BUT POSED GREATER RISKS TO THE FINANCIAL SYSTEM AT THE SAME TIME

This chapter is based on Nijskens and Wagner (2011).

2.1 INTRODUCTION

The world financial system experienced a period of severe crisis in 2008 and 2009. Many of the factors that have contributed to the turmoil, such as loose monetary policy or intense competition, have also been central in previous crises. A key novel element in the current crisis, however, are the various ways through which banks have transferred credit risk in the financial system. Banks traditionally shed only few risks from their balance sheets, such as through loan sales or credit guarantees. This shedding was mainly limited to credits that were informationally less sensitive, such as consumer credit. In recent years, however, banks have dramatically increased their risk transfer activities. For one, they have done this through the use of credit derivatives, and mostly in the form of Credit Default Swaps (CDS). These instruments allow banks to trade credit risks on a variety of exposures. The markets for CDS have grown tremendously since their inception in 1996, with outstanding volumes estimated at around U$ 10 trn before the start of the crisis. Spurred by new financial innovations, banks have also significantly increased their securitization of assets. Particularly noteworthy are the Collateralized Loan Obligations (CLOs) through which banks transfer pools of loans from their balance sheet. While banks have frequently used loan sales to reduce risk in the past, this new technique allowed banks to shed commercial loans (typically the most informationally sensitive form of lending) on a large scale.

The severity and the widespread nature of the current crisis indicate that these risk transfer activities have increased the risks in at least some parts of the financial system. A central question, however, is how this credit risk transfer (CRT) has affected the banks that used it to transfer away risk. After all, the main rationale behind CRT is that it allows fragile financial institutions to move risks to less fragile institutions and to diversify away concentrated exposures. It was mainly for these reasons why regulators initially endorsed these activities (IAIS, 2003; BIS, 2004). If even these institutions did not benefit, there are important implications for the overall stability assessment of the new CRT activities.

In a static sense, a properly done transfer of risk should of course reduce the banks' risks. However, banks are likely to respond to any reduction in their risk. This may be through various methods, such as by increasing their lending (Instefjord, 2005; Wagner, 2007), by reducing their monitoring and screening efforts (Morrison, 2005) or by leveraging up their capital structure (Jiangli and Pritsker, 2008). Banks' responses may also go beyond a pure offsetting of the risk that they have shed. This may be, for example, because the new CRT methods provide banks with effective risk management techniques. For example, CDS can be used to reduce risk concentrations in bank portfolios. Better risk management generally allows banks to operate with riskier balance sheets (Froot et al., 1993). Additionally, these new instruments may make banks less averse to crisis situations. Banks may expect that they can more easily liquify parts of their balance sheet, such as by doing an additional CLO (Cardone-Riportella et al., 2010). This may further encourage risk-taking at banks (Wagner, 2007). Banks may also end up being riskier because they fail to effectively transfer the risk. This may be because a bank keeps the riskiest tranche in a securitization, or because of guarantees (explicit or implicit) given to securitization vehicles.

CRT may also increase bank risk in a systemic sense, even if banks' individual risk does not increase. This is because securitization allows banks to shed idiosyncratic exposures, such as the specific risk associated with their area of lending. The idiosyncratic share in a bank's risk may also be lowered because banks may hedge any undiversified exposures they may have by buying protection using CDS, while simultaneously buying other credit risk by selling protection in the CDS market.[1] Banks may thus end up being more correlated with each other. This may amplify the risk of systemic crisis in the financial system (Elsinger et al., 2006; Acharya and Yorulmazer, 2007; Wagner, 2008) since it increases the likelihood that banks incur losses jointly (a situation experienced in the current crisis). Securitization typically also exposes banks to greater funding risk. Such risks are mostly systemic in nature, as current events have shown, since the markets for securitized assets and the markets for funding those assets may collapse. For example, the problems for securitization vehicles to refinance themselves during 2008 forced banks to provide liquidity lines to these vehicles or take assets back on their balance sheet. Banks additionally suffered because, due to the breakdown of the securitization market, they were no longer able to sell the assets they had originated for securitization purposes. Effectively, banks found risks they transferred away flowing back to their balance sheets.

In this paper we explore some of the aspects of the relationship between CRT activities and the riskiness of banks. For this we focus on bank risk as perceived by the market through bank share prices. We analyze a sample of banks that started trading Credit Default Swaps and a sample of banks that issued Collateralized Loan Obligations between 1997 and 2006. We study whether the adoption of any of the two CRT methods is associated with a change in the bank's perceived risk. Our results indicate that this is the case: the first use of either CLO or CDS is associated with a significant permanent increase in a bank's risk, as measured by its share price beta. The effect is also economically important: the beta at CLO banks increases by 0.21, while for CDS banks it increases by 0.06.[2] Furthermore, the larger effect we find for CLOs (compared to CDS) can be explained by the fact that CLOs allow for the shedding of a much larger variety of exposures (by contrast, the liquid market for CDS is limited to around 600-900 firms worldwide). The adoption of this new CRT tool is hence likely to be also accompanied by a larger response by banks. We also find that CLOs initially

1 In fact, most banks simultaneously buy and sell credit risk in CDS markets.
2 Keeping in mind that share prices reflect expected future profits, this effect should not be interpreted as the direct effect of either CRT method, but as the market's anticipation of a different behaviour of these banks in the future. Interestingly we also find that a sample of matched banks that did not undertake CLOs experienced a decline in their betas. This suggests that CLO banks increased their activities at the expense of other banks.

decrease bank risk. This is plausible since the CLO itself (if it is a true sale) removes a substantial amount of risks from a bank's balance sheet, which may only be later offset by increased bank risk-taking. There is no such negative effect for CDS. Quite to the contrary, CDS even increase bank risk more in the short run. This may be the result of banks actually using CDS to source new credit risk (such as by selling protection in the CDS market).[3] We also find that our results are relatively robust in various subsamples, which are created by splitting CRT banks according to profitability, loan growth and maturity structure of their liabilities.

Next, we study whether the increase in bank risk is due to higher individual bank risk, or due to higher systemic risk. For this we split a bank's beta into its standard deviation relative to the market's standard deviation (individual risk) and its correlation with the market (systemic risk). Perhaps surprisingly, we find that the increase in beta is purely due to an increase in the correlation. The individual risk of CRT banks in fact even goes down. This suggests that the increase in bank risk is not simply due to banks overcompensating the risk they have shed. Rather it is due to the fact that CRT activities expose banks to greater systemic risk.[4]

These findings identify a challenge for financial regulation. Banks engaging in CRT activities seem to pose more systemic risk even though they become individually less risky. Standard measures of bank risk commonly used by regulators, such as the amount of risk-weighted assets, fail to capture this.[5] In fact, due to the diversification presumably achieved by CRT, banks have been able to lower their capital requirements, allowing them to extend their lending and thus contributing to the current turmoil. Our results highlight that in a world characterized by an active transfer of credit risk in the financial system, effective regulation should pay more attention to a bank's contribution to systemic risk, rather than to its individual risk (for a theoretical foundation of such regulation see Lehar (2005) and Wagner (2009)).

3 This is consistent with the fact that banks in our sample buy more credit risk than they sell.

4 Our results are consistent with the findings of Adrian and Brunnermeier (2008) who show that the value at risk conditional on another institution being in distress has increased at financial institutions in recent years.

5 An interesting implication of our analysis is that, even though traditional measures of bank risk may have failed to capture the higher risk at CRT banks, the market seems to have been aware of this since bank betas increased well before the crisis.

Our findings are consistent with other studies that emphasize that credit risk transfer has important effects on bank risk. Franke and Krahnen (2007) and Hänsel and Krahnen (2007) investigate European Collateralized Debt Obligation (CDO) issues and find a (small) positive effect of CDOs on (securitizing) bank betas.[6] Uhde and Michalak (2010) confirm these findings of increasing bank risk using a larger and more comprehensive dataset with European banks. As a possible explanation of this risk increase, Goderis et al. (2007) find that a bank increases its loan-to-asset ratio subsequent to the first issuance of a CLO. Foos et al. (2010) conclude that bank loan growth leads to higher bank risk, including a worsening of the risk-return structure and decreasing bank solvency. Hirtle (2009) shows that U.S. banks which purchase protection using credit derivatives raise their supply of loans. Jiangli and Pritsker (2008) provide evidence that banks increased their risk in response to securitization by increasing their leverage. Marsh (2006) presents evidence that the excess equity return effect of announcing a new bank loan is mitigated when the lending bank actively trades in credit derivatives. This suggests lower bank monitoring and hence higher risk-taking. Keys et al. (2010) find that securitized assets have a higher probability of default than assets with comparable characteristics that are not securitized, consistent with lower screening efforts by banks. In a more general setting, Calmès and Théoret (2010) find that off-balance sheet activities increase a bank's systemic risk. Our findings complement the results of the abovementioned studies, as the identified changes in bank behavior may also contribute to higher systemic risk.

We proceed as follows. The next section describes the data and the methodology. Section 2.3 contains the empirical results. The final section concludes.

2.2 DATA AND METHODOLOGY

We construct two separate datasets for CLO and CDS banks. Information about CLO issuance is obtained from the ABS Alert database. This database contains information on various types of rated securitization around the world. There are 52 banks in this

6 The larger magnitude of our estimates is consistent with the notion that in the current crisis most problems arising from securitization assets originated outside Europe (the U.S. mainly). Indeed, we find that the magnitude of the beta effect is smaller if we constrain our sample to European banks.

database that are reported to have issued at least one CLO between June 1996 (the date of the first CLO ever) and September 2004 (which marks the end of our data set). For each of these banks we obtain the date when they issued their first CLO. We then obtain from Datastream[7] daily equity returns from six months prior to the first CLO date in our dataset to six months after the last date. We drop all banks for which no (or only incomplete) equity data was available. This leaves us with 35 CLO banks with complete share price data, of which 21 are European, 7 are North-American, 6 are Japanese and one is Australian. The sample period we ultimately use for CLO banks runs from January 1997 to March 2005.

Information about CDS trading comes from the U.S. FDIC Call Reports. For each bank that ever trades in CDS after December 1998 (the date from which on banks were required to report their CDS exposure) until September 2005, we identify the quarter in which the bank first started trading CDS. This trading may be on the buy or on the sell side (but typically both dates coincide). There are 82 such banks. However, for banks reporting in the last quarter of 1998 we do not know when they actually started trading, as the requirement to report was only in force from that quarter onwards. Since they could have started trading before this point in time, we have to drop these banks. Then, we again use Datastream to obtain data on daily share prices from 6 months before the first CDS date to 6 months after the last CDS date. This leaves us with 38 CDS banks with complete share price data, of which 9 are European, 25 are North-American, 2 are Asian and 2 are Australian.[8] The sample period we finally use for CDS banks runs from June 1998 to June 2006.[9] We do not include the subprime crisis in our analysis since we are interested in the market's *anticipation* of the risk impact of CRT and not how changes in risk may ultimately materialize. Moreover, including the subprime crisis is likely to introduce substantial noise into the estimation.

Table 2.A.1 shows descriptive statistics for the CLO and CDS datasets. We can see that both sets of CRT activities are fairly large in size, but that CDS activities are

7 All stock and index returns are taken from Thompson Refuters' Datastream service; for more information see http://online.thomsonreuters.com/datastream/

8 Non-U.S. banks enter our sample since they have to report any CDS activities of their U.S. subsidiaries. Note that to the extent banks do not have integrated risk management systems and/or CDS activities are not correlated within the bank, this will bias our estimations against finding an effect of CDS trading.

9 Minton et al. (2009) find that up to 2003 only 19 large banks used CDS. The differences arise, first, because some banks started trading after 2003, and second, because we also consider smaller banks.

on average larger.[10] The average (daily) equity returns for each set of banks during the respective sample periods are around 0.024% and 0.025%, respectively. Figures 2.A.1 and 2.A.2 show the distribution of the CLO and CDS starting dates, respectively. We can see that these dates are well distributed over the entire period, thus creating sufficient time-variation.

We will estimate the relationship between CRT activities and a bank's beta using an augmented CAPM model. For this we use the following regression equation

$$\begin{aligned} R_{i,t} = \; & \alpha_i + \beta_1 R_{M,t} + \delta_i D^{abn} + \beta_2 D^{temp} + \beta_3^{temp} D^{temp} R_{M,t} \\ & + \beta_4 D^{perm} + \beta_5 D^{perm} R_{M,t} + \epsilon_{i,t}. \end{aligned} \tag{2.1}$$

In equation (2.1), α_i is the bank fixed effect and $R_{i,t}$ and $R_{M,t}$ are excess returns over the risk-free rate for bank i and the market portfolio, respectively. The market return is measured by the MSCI World index, as the dataset contains worldwide banks. Both individual bank stock returns and index returns are translated into U.S. Dollars[11]. We use the 3-month US Treasury Bill rate as a proxy for the risk-free return.

Then, D^{abn} is a dummy variable which takes the value of one 20 days before to 20 days after the event date. It is intended to measure any abnormal return associated with the CRT event. For the CLO banks, the event date is the day of the first issuance of a CLO. For the CDS banks, we only know the quarter in which CDS trading started. We hence take the event date to be the middle of that quarter. D^{temp} is a dummy which is equal to 1 in the following 80 days after the event window. This dummy will be used to measure any temporary mean effect of CRT. D^{perm} is a dummy to measure the permanent beta effect, which takes a value of 1 after the end of the event window until the end of the sample period. This dummy will be used to measure the permanent mean effect of CRT. The variables of interest in the regression are the

10 For CLOs, size refers to the total size of the CLO, which does not have to equal the amount shed due to tranche retention by the bank.

11 For this, we have downloaded the returns in U$ format from Datastream. We have also estimated our model using returns in local currency, which yielded very similar results. For the currency conversion of MSCI indices, see http://www.mscibarra.com/eqb/methodology/meth_docs/MSCI_May10_IndexCalcMethodology.pdf

coefficients on the interaction terms $D^{temp}R_{M,t}$ and $D^{perm}R_{M,t}$, which will measure the change in a bank's beta in the 80 days after the event window (temporary effect) and in the total period after the event window (permanent effect), respectively. Note that these dummies are overlapping: the temporary effect will measure the beta effect over and above the permanent effect.

2.3 RESULTS

The estimation results are presented in Table 2.A.2 (Panel A for CLO banks and Panel B for CDS banks). Column 1 contains the results for the baseline model from equation (2.1). Reported significance levels are based on panel-corrected standard errors. In both datasets all the relevant variables are significant, except for the abnormal return captured by coefficient δ. Furthermore, in both datasets the equity returns of banks quite closely follow the market with a beta of 0.84 for CLO and a beta of 0.95 for CDS. The fact that there is no abnormal return associated with the start of CRT activities is interesting, as it suggests that the market does not expect any efficiency gains to be associated with these activities.

The beta effect can be seen from the coefficients on the interaction terms (labeled "Temporary β effect" and "Permanent β effect" respectively). For both CLO and CDS banks we find a strong positive permanent beta effect: for CLO banks the beta increases by 0.21,[12] while for CDS banks it increases by 0.06. For CLO banks, however, there is a negative temporary beta effect of -0.40. Since the dummy periods are overlapping, this indicates that following a CLO the bank beta initially declines by -0.19 (=0.21-0.40), after which it goes up permanently. For CDS banks we have a positive temporary effect of 0.18 on top of the 0.06 from the permanent effect.

The initial reduction in beta associated with CLOs can be explained by the fact that a (true sale) CLO removes loans from a bank's balance sheet, thus lowering bank risk. Only when the bank reacts to this, for example by extending new loans, bank risk may increase later on. This is not the case for CDS, since banks may either buy or sell risk

12 If we constrain the analysis to European banks, this coefficient drops to 0.04. This is consistent with the findings by Hänsel and Krahnen (2007) who obtain a weak effect of CLOs on bank betas using a sample of European CLOs.

using CDS. In fact, the additional temporary CDS effect suggests that banks take on additional risk at the onset of CDS trading. This is consistent with the fact that the accumulated amount of protection selling in the Call Reports available to us is higher than the amount of protection buying.

In column 2 we report results for the baseline model without the temporary effect. This is in order to make sure that our results are not influenced by the overlap of the temporary and permanent dummy. The coefficients for the permanent effect are basically unchanged and are still significant. The beta effect decreases for CLO banks and increases for CDS banks, consistent with a negative temporary effect for CLO and a positive temporary effect for CDS banks; these are now captured by the permanent effect. In column 3 we report results from the baseline model where additionally the excess return of the banking sector over the market return, $R_B - R_M$, is included. The bank sector return R_B is the return on the MSCI World Commercial Bank index in excess of the risk-free rate. The results show that the banking sector is closely followed by the CLO banks ($\beta_4 = 0.96$), but less so for the CDS banks ($\beta_4 = 0.67$). More importantly, we observe that the results for the beta effects do not change much.

Taken together, the size of the estimated coefficients suggests that CRT affects banks substantially, or is at least perceived to do so by the market. Very likely this is not exclusively due to changes banks implement at the time of CRT itself. Rather, the market will also perceive future changes in bank behavior and discount these to the present period. The economic significance of our results is also consistent with the general experience in the crisis of 2008-2009, which suggested that the impact of CRT on bank risk indeed was large. It should furthermore be noted that our estimates are consistent with other studies which also find large effects of CRT. For example, Goderis et al. (2007) find that after the issuance of its first CLO a bank increases its target loan level by 50%.

2.3.1 *Robustness checks*

In this section we carry out various robustness checks for our main result, which is that there is a significant and strong permanent beta effect related to the introduction of CRT activities.

A first alternative explanation of our results is that the increase in betas is not specific to CRT-banks. Instead, banks overall may have experienced an increase in their betas, regardless of whether they undertake CRT activities or not. For this we study the betas of banks which are similar to our CRT banks. More specifically, we match each CRT bank with its closest bank in its jurisdiction (North America, Europe, Asia or Oceania) in terms of asset size at the beginning of the sample. We then replace the returns of our CRT banks with those from the matching banks and run again the baseline regression from equation (2.1).

The results from this exercise are contained in Table 2.A.3. As can be seen, there is a negative permanent effect for the set of banks matched to our CLO banks, while there is no significant effect at all for the matching CDS banks. The negative effect for CLO banks is interesting as it suggests that CRT might have competitive effects: expansion of risk-taking at CLO banks may result in lower lending market share for non-CLO banks. Since CLO-banks are very large banks this is not implausible, as a change in their activities could indeed affect the remaining banks. An alternative interpretation is that CRT is driven by differences in risk appetites: while risk-loving banks undertake CLOs and see their beta increase, risk-averse banks shy away from lending and see their beta decrease.

Besides matched banks, we also study whether there is a general trend towards higher betas in the banking sector during our sample period. We estimate the beta of the MSCI World Bank index with respect to the world market index in 2-year intervals. The results of this regression indicate that, apart from the first 2-year period, the bank sector's beta with respect to the market has been fairly stable; if anything, it has decreased. There is thus no general upwards trend in betas throughout the banking sector. This suggests that CRT banks increased their risk but that this was offset by non-CRT banks.

A related concern is that CRT-banks are somehow different from other banks and that they are characterized by a general increase in their risk over time (unrelated to CRT activities). Since our permanent CRT-dummies increase from zero to one over the sample period for all banks, this could also result in a significant estimation of the permanent dummy. To address this concern we allow for a trend in betas in our baseline model. Results can be found in the last column of Table 2.A.2. The trend is insignificant and both temporary and permanent effects are virtually unchanged. In addition, we have also checked robustness to a potentially non-linear trend by including yearly-beta effects (interacting $R_{M,t}$ with year dummies). Again, there are no noteworthy changes in the results. Finally, we have carried out a Monte-Carlo simulation to check robustness. For this we have simulated stock returns under the assumption of a linear trend in bank betas, using bank-specific variances estimated from our sample. Performing our regression analysis with these simulated returns shows that temporary and permanent beta effects are on average insignificant. Furthermore, the proportion of significant coefficients is close to the chosen significance level (i.e. 5% is significant at the 5% level), further corroborating the robustness of our results. More details can be found in section 2.A.3.

Another interesting question is whether our results are driven by a specific subgroup of banks, or whether they seem to apply to banks undertaking CRT more generally. To test this we split our sample according to various criteria and re-estimate the baseline model for each subsample. Results are contained in Table 2.A.4, which only reports the coefficients and significance of the permanent beta effect as we focus on this result.

This table first reports regression results for a breakdown by region, contained in row 1. We separate into two regions, namely the United States and the rest of the world (EU, Asia and Oceania). This exercise shows that our result holds quite generally: apart from the CDS banks in the US, we find that a permanent beta increase ensues. An interesting result is that the change for US CLO banks is quite large, possibly reflecting the large role securitization plays in US markets.

Then, we report regression results for a breakdown by asset size (row 2 in the table). For this we split the sample in three groups depending on asset size and run regressions for each group. A clear picture emerges. We find that regardless of the source of CRT, the permanent effect increases with asset size: the group of large banks has a coefficient larger than the middle group, which in turn is larger than the small banks (for which coefficients are even insignificant). This is plausible as large banks dominate securitization and derivatives markets. Hence, we would expect the impact for these banks to be more pronounced.

Third, we split by Return on Assets (ROA, the third row in the table). We find that for each of the six subgroups of banks CRT significantly increases betas, except for the high ROA group of CDS banks. For these banks there is a negative beta effect. Comparing the different groups one can see that the beta-effect is quite uniform across ROA groups, apart from the last column. The negative coefficient for the banks with the highest ROA may reflect that these banks have high franchise values to protect and use CDS to protect against defaults on their portfolios rather than to source new risks.

Fourth, we do a breakdown by the loan-to-asset ratio of banks (fourth row). The permanent effect comes out significantly in five out of the six groups, with the only exception being the intermediate group of CDS banks. We see that the effect is the strongest for the banks with the largest and smallest loan ratio. This suggests that the effect does not seem to rely on the specific lending business model of the bank.

Fifth, we break down by past asset growth. The permanent effect is significant and positive for four of the six subgroups. For CLO banks with intermediate asset growth there is no significant effect, while for the fastest growing CDS banks there is a negative effect that is significant. This is surprising to the extent that one would expect fast-growing banks to become also more risky. A possible explanation, however, is that these banks had already taken a lot of risk in the past, hence starting out with a high beta. They may then have in fact used securitization to stabilize their balance-sheet and to off-load risk.

Sixth, moving to the liability side we break down by the ratio of deposit and short-term funding to total assets (a measure of fragility of bank funding). We find a significant and positive beta effect for four of the subgroups. The exceptions here are the group of CLO banks with a low fragile funding ratio, and those CDS banks that have a high share of fragile funding. For these groups there is no significant effect. Comparing the various coefficients, no clear picture emerges for how liability structure affects the permanent effect.

We can thus conclude that our results are not driven by a specific group of banks and seem to hold quite generally for banks undertaking CRT.

Then, we carry out some final robustness checks. First, plausible variations in the length of the event window do not influence the beta effect much (at most 0.01 for both the temporary and the permanent effect). For the CDS data, we also change the position of the event window from centered at the middle of the quarter to either the beginning or the end of the quarter. This does not affect the results noticeably. Second, changing the captured period of the temporary dummy does not have a significant effect on the coefficients either. Finally, we also control for the presence of outliers in our stock return data. For this we winsorize the banks' equity returns at 1% and 2.5% on each side. This does not yield any different results: the permanent effect is virtually unchanged, while the temporary effect changes by only 0.01. Both effects remain significant.

2.4 BETA DECOMPOSITION

We will now analyze the source of the change in the banks' betas. For this we decompose a beta into a variance and a correlation component, and analyze which part is responsible for the increase in banks' betas.

The beta of a stock is given by

$$\beta_i = \frac{cov_{i,M}}{\sigma_M^2}, \tag{2.2}$$

where $cov_{i,M}$ is the covariance of the stock with the market return and σ_M^2 is the variance of the market. Using that the correlation coefficient between the stock and the market is defined as

$$\rho_{i,M} = \frac{cov_{i,M}}{\sigma_i \cdot \sigma_M}, \tag{2.3}$$

we can rewrite the beta equation as follows:

$$\beta_i = \rho_{i,M} \frac{\sigma_i}{\sigma_M}. \tag{2.4}$$

This equation shows that the beta is the product of a bank's correlation with the market and its standard deviation relative to that of the market (the relative standard deviation). A change in the beta may thus be triggered by a change in either component.

We next estimate whether CRT has led to a change in bank correlations. To this end we normalize the share price and market returns by using their respective standard deviations. By doing this, we obtain a series with a variance of one. From equation (2.4) we then have that the estimated regression coefficient of these transformed returns equals the correlation of the original series, since the relative standard deviation equals one.

This normalization can be implemented in the baseline model in the following way, where a tilde represents a transformed series:

$$\begin{aligned} \widetilde{R}_{i,t} = \ & \alpha_i + \rho_{1i}\widetilde{R}_{M,i,t} + \delta_i D^{abn} + \rho_2 D^{temp} + \rho_3^{temp} D^{temp} \widetilde{R}_{M,i,t} \\ & + \rho_4 D^{perm} + \rho_5^{perm} D^{perm} \widetilde{R}_{M,i,t} + \epsilon_{i,t}, \end{aligned} \tag{2.5}$$

where

$$\widetilde{R}_{i,t} = \begin{matrix} R_{i,t}/\sigma_{i,t<t_i} \text{ if } t < t_i \\ R_{i,t}/\sigma_{i,t\geqslant t_i} \text{ if } t \geqslant t_i \end{matrix} \quad \text{and} \quad \widetilde{R}_{M,i,t} = \begin{matrix} R_{M,i,t}/\sigma_{M,t<t_i} \text{ if } t < t_i \\ R_{M,i,t}/\sigma_{M,t\geqslant t_i} \text{ if } t \geqslant t_i \end{matrix} \tag{2.6}$$

and t_i denotes the event date. Note that in the computation of the normalized variables we allow standard deviations to differ before and after the event date. Note also that $\widetilde{R}_{M,i,t}$ is now bank-specific because the variance correction depends on the event date.

Table 2.A.5 contains the estimation results, in the same way as Table 2.A.2. For ease of comparison we focus on the baseline model without the temporary effect (column 2). It can be seen that either method of CRT is associated with a significant permanent

increase in the correlation: the respective coefficients are 0.22 for CLO banks and 0.19 for CDS banks. From this we can conclude that the increase in beta is at least partly driven by an increase in correlations among banks.

Finally, we ask the question of how much of the increase in the beta is due to the correlation effect (a change in $\rho_{i,M}$) and how much due to the variance of banks relative to the market (a change in $\frac{\sigma_i}{\sigma_M}$). For this we derive an expression for the change in the relative variance. Denoting with superscripts 0 and 1 the time before and after the event date, and with Δ the change in a variable, we can express the beta after CRT as follows: $\beta^1 = \beta^0 + \Delta\beta$. Using that $\beta^1 = \rho^1_{i,M}\frac{\sigma^1_i}{\sigma^1_M} = (\rho^0_{i,M} + \Delta\rho_{i,M})\frac{\sigma^1_i}{\sigma^1_M}$ and rearranging we obtain an expression for the relative variance after CRT:

$$\frac{\sigma^1_i}{\sigma^1_M} = \frac{\beta^0 + \Delta\beta}{\rho^0_{i,M} + \Delta\rho_{i,M}}. \tag{2.7}$$

The change in $\frac{\sigma_i}{\sigma_M}$ can hence be expressed as

$$\Delta\frac{\sigma_i}{\sigma_M} = \frac{\sigma^1_i}{\sigma^1_M} - \frac{\sigma^0_i}{\sigma^0_M} = \frac{\beta^0 + \Delta\beta}{\rho^0_{i,M} + \Delta\rho_{i,M}} - \frac{\beta^0}{\rho^0_{i,M}}. \tag{2.8}$$

From this equation we can compute the change in the relative variance. We do this using the estimated coefficients for the market return and for the permanent effect in column 1 of both panels of Table 2.A.2 as estimates of β^0 and $\Delta\beta$, and the corresponding coefficients in Table 2.A.5 as estimates for $\rho^0_{i,M}$ and $\Delta\rho_{i,M}$. We find that the relative variance for both set of banks declined on average: for CLO banks we have $\Delta\frac{\sigma_i}{\sigma_M} = -2.43$ and for CDS banks $\Delta\frac{\sigma_i}{\sigma_M} = -1.37$.

This implies that the beta increase is exclusively driven by an increase in bank correlations. The change in the relative variance even had an offsetting effect on betas.

2.5 CONCLUSION

In this paper we have analyzed the relationship between CRT activities at banks and their riskiness as perceived by the market. We have found that the market considers CRT banks to be substantially riskier: banks which issue their first CLO experience an increase in their beta by 0.21, while banks which start trading in CDS see their beta rise by 0.06. This difference can be explained by the fact that CLOs can take loans off the balance sheet, while CDS do not. Interestingly, we also found that the increase in the beta is due to a higher correlation between banks and not due to higher bank volatility. In other words: while banks individually look less risky (since their volatility declines), they paradoxically pose more risk (since their correlation and beta increases).

This has important implications for an effective regulation of these institutions. It highlights the need to regulate institutions not only according to their individual risk, but also according to their contribution to systemic risk. Another interesting implication of our results is that the market seems to have been aware of the greater risk these banks are posing. This is because the banks experienced a substantial increase in their beta well before the onset of the crisis. Together with the failure of traditional risk measures to spot the higher systemic risk at CRT banks, our results warrant a greater future role for using market-based information for financial regulation.

2.A APPENDIX

2.A.1 *Tables*

Table 2.A.1: Descriptive statistics for the CLO and CDS datasets

Panel A: CLO Banks

	Transaction Amount (in thousands of US $)	Bank Equity Return (daily, in %)
Mean	1,203,354	0.0240
Median	539,000	-0.0047
Std. Deviation	1,386,848	2.3709
Minimum	10,000	-19.9815
Maximum	5,500,000	21.3601

Panel B: CDS Banks

	Transaction Amount (in thousands of US $)	Equity Return (daily, in %)
Mean	4,641,339	0.0246
Median	104,881	-0.0052
Std. Deviation	19,901,444	2.0691
Minimum	7	-40.5592
Maximum	123,851,000	40.5345

Table 2.A.2: Beta estimation results

Panel A: CLO Banks

	(1)	(2)	(3)	(4)
Market β	0.8421***	0.8420***	0.8492***	0.9703***
	(19.43)	(19.39)	(20.95)	(6.87)
Mean Trend				-0.0000
				(-0.30)
β Trend				-0.0001
				(-1.06)
Abnormal Return	-0.0006	-0.0006	-0.0006	-0.0005
	(-0.88)	(-0.90)	(-0.89)	(-0.73)
Temporary Mean Effect	-0.0006		-0.0004	-0.0007
	(-1.22)		(-0.74)	(-1.51)
Temporary β Effect	-0.3977***		-0.4171***	-0.4035***
	(-6.25)		(-6.61)	(-6.34)
Permanent Mean Effect	0.0002	0.0002	-0.0001	0.0004
	(0.57)	(0.45)	(-0.15)	(1.16)
Permanent β Effect	0.2136***	0.1930***	0.2370***	0.2389***
	(5.53)	(5.01)	(6.35)	(6.84)
Bank Sector Excess Return			0.9641***	
			(19.44)	
Observations	68565	68565	68565	68565
R^2	0.09	0.09	0.12	0.09
Number of banks	35	35	35	35

The dependent variable is the daily individual bank stock return in excess of the risk-free rate. The regression coefficients in column (1) are as in equation (2.1). Column (2) reflects the exclusion of the temporary effect, as in the text. Column (3) adds the bank sector excess return to the baseline model. Column (4), finally, reports the baseline model augmented with a time trend. Z-statistics from PCSE are reported in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Panel B: CDS Banks

	(1)	(2)	(3)	(4)
Market β	0.9453***	0.9452***	0.9626***	1.0100***
	(37.20)	(37.21)	(40.53)	(13.06)
Mean Trend				0.0000
				(0.10)
β Trend				-0.0001
				(-1.00)
Abnormal Return	-0.0000	-0.0000	-0.0000	-0.0000
	(-0.01)	(-0.06)	(-0.01)	(-0.00)
Temporary Mean Effect	-0.0004		-0.0001	-0.0004
	(-0.91)		(-0.33)	(-0.96)
Temporary β Effect	0.1837***		0.2005***	0.1733***
	(3.30)		(3.69)	(3.17)
Permanent Mean Effect	0.0002	0.0002	-0.0001	0.0002
	(0.67)	(0.58)	(-0.17)	(0.83)
Permanent β Effect	0.0595**	0.0694***	0.0656***	0.0748***
	(2.56)	(3.07)	(2.92)	(4.10)
Bank Sector Excess Return			0.6742***	
			(16.66)	
Observations	77167	77167	77167	77167
R^2	0.13	0.13	0.14	0.13
Number of banks	38	38	38	38

The dependent variable is the daily individual bank stock return in excess of the risk-free rate. The regression coefficients in column (1) are as in equation (2.1). Column (2) reflects the exclusion of the temporary effect, as in the text. Column (3) adds the bank sector excess return to the baseline model. Column (4), finally, reports the baseline model augmented with a time trend. Z-statistics from PCSE are reported in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Table 2.A.3: Matching with banks not using CRT

	CLO	CDS
Market β	1.1231***	0.9744***
	(28.09)	(25.34)
Abnormal Return	-0.0004	-0.0009
	(-0.57)	(-0.94)
Temporary Mean Effect	0.0001	-0.0001
	(0.25)	(-0.10)
Temporary β Effect	-0.0045	0.0263
	(-0.07)	(0.36)
Permanent Mean Effect	0.0002	0.0004
	(0.57)	(1.05)
Permanent β Effect	-0.2092***	-0.0136
	(-5.68)	(-0.33)
Observations	64756	77608
R^2	0.084	0.04
Number of banks	35	38

The dependent variable is the daily individual bank stock return in excess of the risk-free rate for banks not engaging in CRT. The regression coefficients are as in equation (2.1). Z-statistics from PCSE are reported in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Table 2.A.4: Breakdown

By:	CLO			CDS		
	US	EU/Asia/Oceania		US	EU/Asia/Oceania	
Region	0.5856***	0.1206***		-0.0282	0.2989***	
	(10.72)	(2.81)		(-1.02)	(7.79)	
	Small	Medium	Large	Small	Medium	Large
Total Assets	0.0592	0.2129***	0.5616***	-0.0168	0.0802***	0.2785***
	(0.75)	(4.67)	(6.17)	(-0.48)	(2.71)	(6.84)
ROA	0.1960**	0.1458**	0.1903***	0.3889***	0.3849***	-0.1347***
	(2.47)	(2.46)	(4.23)	(9.94)	(8.95)	(-4.35)
Loans/Assets	0.2031***	0.0847*	0.3039***	0.0876***	0.0507	0.3575***
	(3.26)	(1.83)	(4.37)	(2.77)	(1.55)	(8.08)
Past Asset Growth	0.3408***	0.0380	0.6051***	0.1062***	0.3274***	-0.1662***
	(4.10)	(0.75)	(6.47)	(3.24)	(7.66)	(-3.41)
(Dep&ST)/Assets	0.0773	0.0783**	0.5827***	0.1309***	0.2060***	-0.0129
	(0.90)	(2.29)	(10.09)	(3.40)	(6.63)	(-0.43)

The regression analysis performed is the one from equation (2.1). For ease of exposition we only report our main variable of interest, namely the permanent β effect. Z-statistics from PCSE are reported in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Table 2.A.5: Correlation estimation results

Panel A: CLO Banks

	(1)	(2)	(3)	(4)
Market ρ	0.1635***	0.1634***	0.1460***	0.1111***
	(17.98)	(17.97)	(17.26)	(5.12)
Mean Trend				-0.0000
				(-0.31)
ρ Trend				0.0001***
				(3.30)
Abnormal Return	-0.0151	-0.0160	-0.0268	-0.0172
	(-0.56)	(-0.59)	(-1.00)	(-0.64)
Temporary Mean Effect	-0.0255		-0.0152	-0.0244
	(-1.20)		(-0.74)	(-1.20)
Temporary ρ Effect	-0.1000***		-0.1072***	-0.0996***
	(-4.52)		(-4.87)	(-4.50)
Permanent Mean Effect	0.0293*	0.0268	0.0113	0.0257*
	(1.65)	(1.58)	(0.68)	(1.70)
Permanent ρ Effect	0.2250***	0.2202***	0.2520***	0.1906***
	(20.06)	(19.80)	(23.71)	(20.70)
Bank Sector ρ			0.1504***	
			(19.22)	
Observations	68565	68565	68565	68565
R^2	0.100	0.100	0.123	0.101
Number of banks	35	35	35	35

The dependent variable is the daily individual bank stock return, in excess of the risk free rate and adjusted according to equation (6). The regression coefficients in column (1) are as in equation (2.5). Column (2) reflects the exclusion of the temporary effect, as in the text. Column (3) adds the bank sector excess return, adjusted in the same manner as the market return, to the baseline model. Column (4), finally, reports the baseline model augmented with a time trend. Z-statistics from PCSE are reported in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Panel B: CDS Banks

	(1)	(2)	(3)	(4)
Market ρ	0.2671***	0.2671***	0.2673***	0.1793***
	(31.58)	(31.55)	(33.96)	(9.39)
Mean Trend				-0.0000
				(-0.06)
ρ Trend				0.0001***
				(6.02)
Abnormal Return	0.0138	0.0146	0.0150	0.0085
	(0.54)	(0.57)	(0.60)	(0.34)
Temporary Mean Effect	-0.0237		-0.0105	-0.0194
	(-1.24)		(-0.56)	(-1.04)
Temporary ρ Effect	-0.1094***		-0.1151***	-0.0833***
	(-7.03)		(-7.61)	(-5.47)
Permanent Mean Effect	0.0261*	0.0236	0.0071	0.0185
	(1.66)	(1.57)	(0.48)	(1.44)
Permanent ρ Effect	0.1964***	0.1852***	0.2057***	0.1513***
	(21.54)	(21.32)	(23.45)	(20.79)
Bank Sector ρ			0.1277***	
			(17.69)	
Observations	77167	77167	77167	77167
R^2	0.148	0.148	0.165	0.150
Number of banks	38	38	38	38

The dependent variable is the daily individual bank stock return, in excess of the risk free rate and adjusted according to equation (6). The regression coefficients in column (1) are as in equation (2.5). Column (2) reflects the exclusion of the temporary effect, as in the text. Column (3) adds the bank sector excess return, adjusted in the same manner as the market return, to the baseline model. Column (4), finally, reports the baseline model augmented with a time trend. Z-statistics from PCSE are reported in brackets. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

2.A.2 *Figures*

Figure 2.A.1: Distribution of first CLO issuances

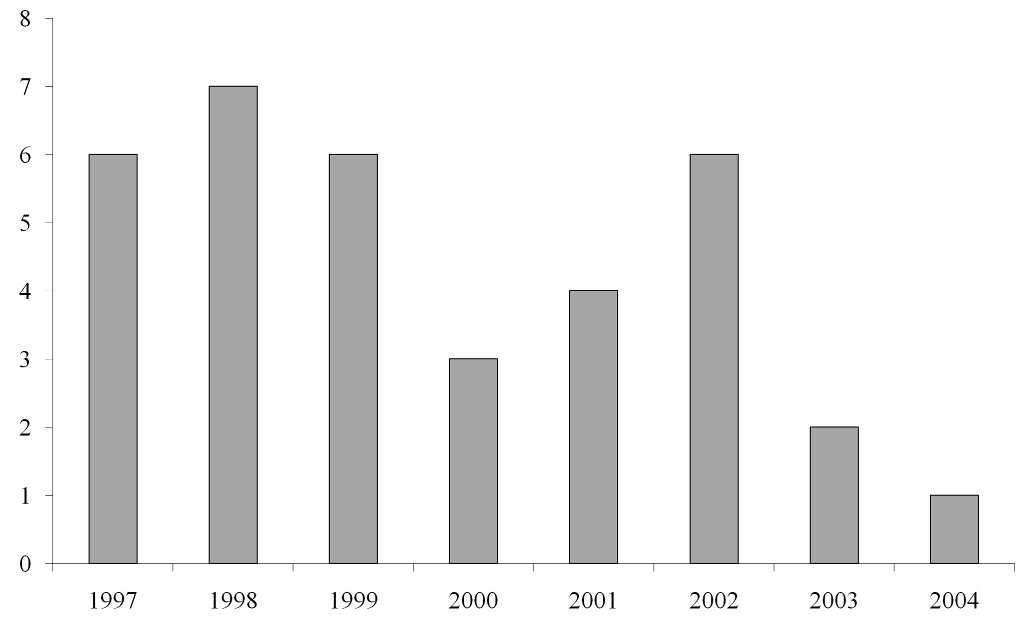
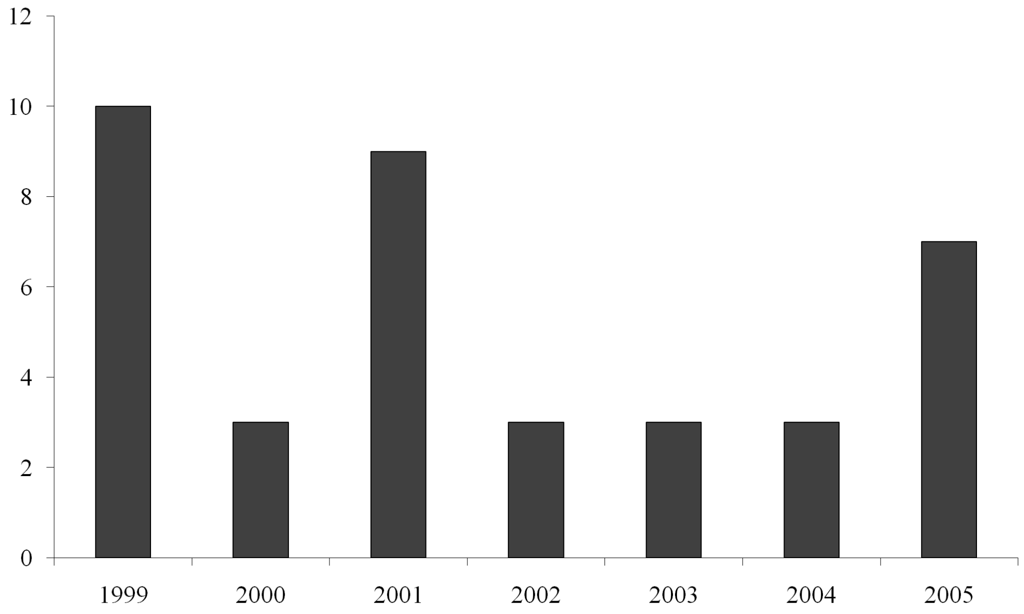


Figure 2.A.2: Distribution of first CDS engagements



2.A.3 *Monte-Carlo simulations*

We first perform a CAPM regression augmented with a trend to obtain an idea about reasonable coefficients that can be used for the data generation process in the simulations. In particular we run a regression of the form

$$R_{i,t} = \beta_0 T + (\beta_1 + \beta_2 * T) R_{M,t} + \epsilon_{i,t}$$

where T represents a time trend. Based on the results we have decided to to use the following parameters for the simulations: $\beta_0 = 0$ (no trend in returns), $\beta_1 = 1$, $\beta_2 = 0.0001$ (this beta time trend implies an increase in betas of 0.2 over the sample period).

The data generating process for the MC simulations then looks as follows:

$$\tilde{R}_{i,t} = (1 + 0.0001 * T) R_{M,t} + \eta_{i,t}$$

where $\tilde{R}_{i,t}$ are the generated individual stock returns. $\eta_{i,t}$ is an error term that is normally distributed with mean 0 and standard deviation σ_i, i.e. $\eta_{i,t} \sim N(0, \sigma_i)$. The σ_i are computed from the sample variance of our original data and are bank-specific.

After simulating the data, we perform our panel fixed effects estimation with PCSE. We stopped after 1000 runs since the results were quite clear. Table 2.A.6 reports the mean of the coefficients and z-statistics, together with the fraction of significant coefficients. We first find that our parameters indicating presence of a β change are insignificant on average. Second we find that the frequency of significant dummies is close to the assumed significance level. For example, the percentages of permanent dummies that are significant at the 5% level are 4.5% and 10% for CLOs and CDS, respectively. The MC simulation thus confirms the validity of our empirical specification.

Table 2.A.6: Monte Carlo results

Panel A: CLO Banks

	Mean Coefficient (Z-statistic)	Fraction significant (at 1 % level)	Fraction significant (at 5 % level)
Market β	1.00213***	1.000	1.000
	(16.66198)		
Mean Trend	-0.00000	0.009	0.064
	(-0.04674)		
β Trend	0.00010**	0.347	0.604
	(2.22159)		
Abnormal Return	-0.00003	0.008	0.051
	(-0.03952)		
Temporary Mean Effect	-0.00001	0.012	0.058
	(-0.02791)		
Temporary β Effect	0.00004	0.009	0.049
	(0.00029)		
Permanent Mean Effect	0.00001	0.013	0.055
	(0.04674)		
Permanent β effect	-0.00042	0.007	0.045
	(-0.01211)		

The regressors are as defined in the paper. The second and third columns of each panel denote the number of significant coefficients as a fraction of the number of simulations. Z-statistics are reported in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

Panel B: CDS Banks

	Mean Coefficient (Z-statistic)	Fraction significant (at 1 % level)	Fraction significant (at 5 % level)
Market β	0.70834***	1.000	1.000
	(23.29417)		
Mean Trend	0.00000	0.010	0.049
	(0.07350)		
β Trend	0.00007***	0.449	0.687
	(2.44186)		
Abnormal Return	0.00008	0.011	0.055
	(0.16819)		
Temporary Mean Effect	0.00004	0.006	0.041
	(0.11380)		
Temporary β Effect	-0.01172	0.002	0.047
	(-0.21577)		
Permanent Mean Effect	-0.00002	0.010	0.059
	(-0.12221)		
Permanent β effect	0.01262	0.022	0.103
	(0.69868)		

The regressors are as defined in the paper. The second and third columns of each panel denote the number of significant coefficients as a fraction of the number of simulations. Z-statistics are reported in parentheses. ***, ** and * denote significance at the 1%, 5% and 10% level respectively.

3

COMPLEMENTING BAGEHOT: ILLIQUIDITY AND INSOLVENCY RESOLUTION

This chapter is based on Eijffinger and Nijskens (2011).

3.1 INTRODUCTION

The financial crisis of 2008 and 2009 has shown the inability of banking regulation and supervision to cope with large shocks to the financial system. To begin with, central banks around the world have had to provide substantial amounts of liquidity to alleviate liquidity shortages, even to banks that were in fact insolvent. This goes against the principle advocated by Bagehot (1873): insolvent banks should not be provided with liquidity. However, as these banks constituted a risk for the financial system as a whole, central banks had to save them.

In addition to the liquidity provision by central banks, governments around the world have constructed very large rescue packages consisting of capital injections into banks, all-out nationalizations, explicit guarantees on bank lending and purchases of troubled assets. During 2009, total resources committed in these packages amounted to €5 trillion or 18.8% of GDP for 11 large western countries[1], whereas actual outlays were €2 trillion (Panetta et al., 2009) at that time. For some smaller countries, like the Netherlands, Denmark or Belgium, recapitalisation efforts and debt guarantees even amounted to around 30% of GDP (Levy and Schich, 2010). Nevertheless, this large-scale intervention has turned out to be absolutely necessary to restore confidence and stability.

1 Australia, Canada, France, Germany, Italy, Japan, the Netherlands, Spain, Switzerland, the United Kingdom and the United States.

Naturally, the academic literature on the Lender of Last Resort (LLR) and bank bailouts has increased tremendously after these events. Traditionally this literature has focused on the principle proposed by Bagehot (1873): a central bank acting as a Lender of Last Resort should provide liquidity freely to illiquid (but solvent) banks, against good collateral and at a penalty rate[2].

A classic critique of this principle is that with modern, well-functioning financial markets a Lender of Last Resort is not necessary anymore: a solvent bank in need of liquidity can go to the interbank market (Goodfriend and King, 1988; Kaufman, 1991). However, the recent financial crisis showed that in bad times, the interbank market may stop functioning. This may happen because of bad asset quality (Brunnermeier and Pedersen, 2009), aggregate uncertainty about fundamentals (Holmstrom and Tirole, 1998) and the resulting inability of market participants to distinguish liquidity from solvency problems. These may lead to coordination failures (Rochet and Vives, 2004; Freixas et al., 2004). As Rochet and Vives (2004) find, coordination failures cause interbank market participants to stop lending to a bank when its fundamentals fall below a certain threshold, although the bank may still be solvent. This suggests a role for the CB as an LLR, providing liquidity to increase confidence of financial markets.

However, regulators also face similar problems in determining whether they should assist a bank or not (Goodhart, 1988), since banks are often better informed about the quality of their assets than regulators are. Because of the inability to discriminate between liquidity and solvency problems, banks may be inefficiently closed or left open (Boot and Thakor, 1993; Rochet, 2004). Freixas et al. (2004) thoroughly examine this issue, assuming that the Central Bank (CB) cannot determine ex ante whether the bank is only illiquid or also insolvent. Their results show that a CB providing LLR support is optimal when insolvent banks are not detected by the market (Rochet and Vives, 2004), it is costly for banks to screen borrowers, and interbank market spreads are high. This resembles crisis episodes with inefficient market discipline, such as the recent financial crisis.

2 A good overview of two decades of research on LLR and closure policy has been provided by Freixas and Parigi (2008).

Also, moral hazard by the bank may ensue: as it is provided with liquidity it can take on more risk than it would otherwise do. Bagehot's remedy for this is to levy a penalty rate. However, in most financial crises this has not been the case. During the recent financial crisis, for instance, the Fed and the ECB lent freely, but not at a penalty rate. Indeed, several authors have found that penalty rates may even increase moral hazard. Repullo (2005), for instance, finds that the existence of a lender of last resort in itself does not create moral hazard, but the introduction of a penalty rate does. More recently, Castiglionesi and Wagner (2011) find that a bank that receives liquidity at a penalty rate exerts less effort to avoid insolvency, as the cost difference between illiquidity and insolvency will be lower.

Finally, the literature has recently considered the effect of systemic shocks on LLR practices. Rochet (2004), for instance, analyzes the optimal LLR policy in the presence of macroeconomic shocks. Banks with a shock exposure above a certain threshold are perceived as too risky and should not receive liquidity assistance. However, this threshold rule is time inconsistent, leading to ex post regulatory forbearance. More recently, Acharya and Yorulmazer (2007, 2008) have considered the correlation between banks' investments and its effect on LLR policy. Ex ante, the CB would want to let correlated banks fail to discipline them. It is, however, not able to credibly commit to this policy: another time inconsistency problem.

We will, however, not study interactions between multiple banks but focus on the interaction between this bank and multiple regulators. Furthermore, our analysis does not focus explicitly on the recent system-wide financial crisis; it is a game between a single bank and a regulator. Repullo (2000) studies this interaction in the context of the lender of last resort function, while Kahn and Santos (2005) additionally consider the authority to close the bank. In both models regulator's choices are based on imperfectly observable information. Both analyses find that, to mitigate forbearance, the CB should be the LLR in case of small shocks and the Deposit Insurance Fund (DIF) should fulfil this role in case of large shocks.

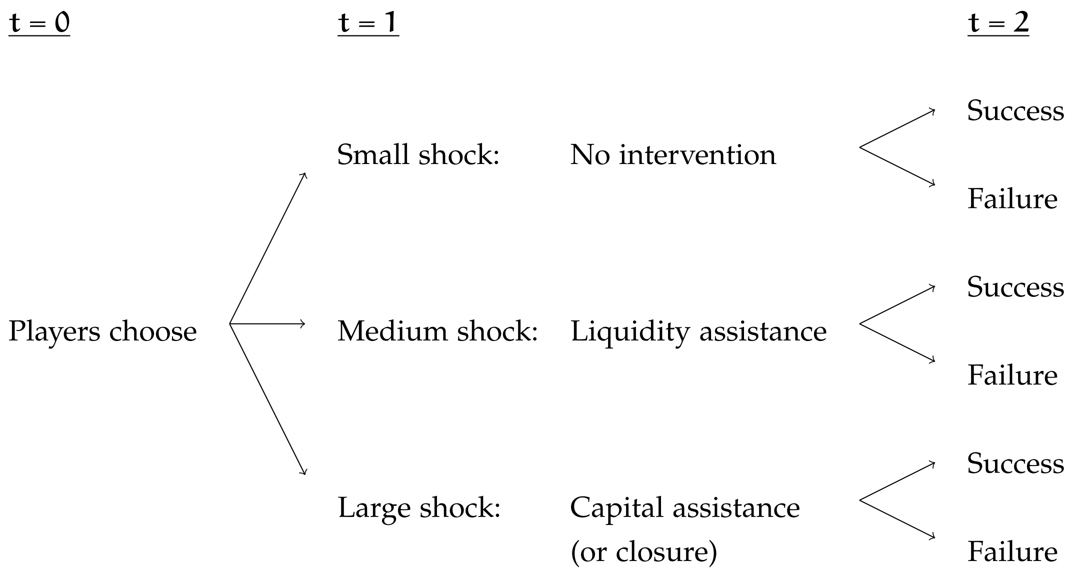
We extend this idea to incorporate prompt corrective action (PCA), as recently analyzed by Kocherlakota and Shim (2007) and Shim (2011). There is one authority who should decide, at a certain threshold level of liquidity problems, whether the bank remains open or should be closed. In case it remains open, the closure authority should provide capital or guarantees to warrant liquidity provision. This resembles the recent crisis, in which fiscal authorities have provided capital or guarantees to keep banks afloat. The analytical model in this paper will provide a framework to perform a simultaneous analysis of liquidity provision and solvency assistance. Furthermore, our analysis incorporates two principles regarding lender of last resort practices. One is the abovementioned principle of Bagehot, stating that central banks should only provide liquidity to solvent banks. The other, complementing Bagehot's doctrine, is the idea that bailout assistance (e.g. capital injections or loan guarantees) should be made costly for banks (Eijffinger, 2008), as a punishment for threatening financial stability.

The results of our analysis show that without any safety net, banks take excessive risk and hoard too much liquidity relative to the social optimum. The introduction of a central bank providing liquidity can decrease excessive liquidity hoarding, but also leads to engagement in moral hazard by banks. To alleviate the moral hazard problem we extend the rescue measures to comprise also assistance by a fiscal authority, which can be made costly for banks. Ultimately we find that the nature of this assistance depends on the weight the fiscal authority attaches to the costs of bank failure. Little concern for bank failure leads to a capital injection at a fixed premium. This alleviates the moral hazard problem, while the bank also invests more in productive assets. A fiscal authority that is very concerned about financial stability will demand a share in bank equity claims. This also decreases moral hazard and leads to an increase in investment. By providing solvency assistance at a premium, be it through debt or equity assistance, the fiscal authorities can provide monitoring and investment incentives to the bank. Knowing that it will receive this assistance (provided it monitors well enough), the bank does not have to keep liquidity and can invest more in productive assets. In the next section, we will introduce our analytical framework in an informal way, before setting up our formal model.

3.2 METHODOLOGY

We model a bank that is systemically important by nature and thus generates negative externalities if it would fail. This bank operates with given deposits (fully insured) and capital (provided by the bank owner). The bank chooses its investment and monitoring effort. The long term investment asset is risky, but productive. Its counterpart, a storage technology or liquid reserve, is riskless and unproductive, but protects against potential liquidity shocks[3]. Furthermore, monitoring of investments increases the probability of success, but reduces the profitability of investment.

Figure 3.1: Sequence of events



The sequence of events that follows the bank's choices is depicted in Figure 3.1. As follows from this figure, the return on investment realizes in the last stage of the sequence ($t = 2$). If the bank fails here (due to a bad result), or at any earlier stage, it will be taken over by the Deposit Insurance Fund (DIF) and the bank owner loses all

3 This can also be viewed as making use of existing credit lines, for example on the interbank market or at the central bank.

capital. The remaining assets of the bank will be used to paid off depositors, while the DIF covers the rest. We assume that deposit insurance is provided exogenously.

It should be noted that the insurance of deposits generates moral hazard if it is not fairly priced. As we assume the liability side of the bank to be fixed and deposit insurance is exogenous, this may well be the case. However, we take this effect as given and focus on the moral hazard that may be generated by liquidity and solvency assistance, additional to the effect of deposit insurance, as described below.

At an intermediate stage ($t = 1$), the bank learns about its future return on the long term asset; this is information private to the banker. In Figure 3.1 we can also see that at this intermediate stage, the bank can suffer from a liquidity shock. This liquidity shock leads to depositors withdrawing a fraction of their deposits (because of an exogenous need for liquidity)[4]. When the shock is small, the bank can resolve it with its own reserves. However, when the shock is of medium size, the bank cannot cope with the liquidity shock on its own. As we have assumed there is no functioning interbank market (we are in a crisis), the bank has to apply for emergency liquidity at the Central Bank (CB). This CB performs two functions: it is the bank's supervisor and the Lender of Last Resort (LLR), in the manner advocated by Bagehot[5]. In its capacity as a supervisor, the CB receives an imperfect signal on bank solvency (partly revealing the banker's private information). Through this signal the CB will get more information on bank solvency, but is not able to tell whether the illiquid bank is solvent or not. More details on the signal will be given in section 3.3. When acting as LLR, the CB can use this signal as an input to minimize its own loss function. It decides whether to assist the bank by weighting the expected benefits and costs of providing emergency liquidity. As soon as the shock is too large to warrant a liquidity injection, the CB will stop providing liquidity.

4 Taking the credit crisis as a reference point, this kind of liquidity shock is very similar to investors in asset-backed securities selling their claims back to the bank. Banks were obliged to return the money, which led to severe liquidity problems. We can see this as analogous to deposit withdrawals, be it by retail depositors or wholesale investors (Rochet and Vives, 2004).

5 This CB can be seen as an institution with a more general mandate for supervision and macroprudential policy, or financial stability.

When the CB stops providing liquidity the Fiscal Authority (FA), who is the third player in our model, will decide on the bank's fate[6] . This authority has bank resolution powers, which the CB does not have. This means that the FA can close the bank or leave it open; in the latter case it will have to inject capital to improve the bank's solvency position. This type of assistance by the FA resembles the bank-specific measures (such as recapitalization, guarantees or nationalization) that many governments have taken during the financial crisis. Note that we abstract from system-wide capital provision efforts such as the Trouble Assets Relief Program (TARP) in the US; for a rigorous analysis of the effect of these programmes see Bhattacharya and Nyborg (2010), Farhi and Tirole (2012) or Philippon and Schnabl (2012).

However, as we have seen during the crisis, the involvement of government in rescuing banks has caused a lot of public indignation. To capture this phenomenon, we assume that the FA can demand a premium return on its assistance. The FA can demand two types of repayment. First, it can set an ex ante premium on its support; this premium depends positively on the importance the FA attaches to preventing bank failure. This can be interpreted as providing assistance in the form of senior debt or guarantees. Second, it can demand a stake in period 2 bank value, effectively becoming an equity claimant in the bank. Many government authorities have employed this form of individual bank assistance during the financial crisis of 2008/2009, with nationalization as a limit case (100% equity claim). Which of these two types of repayment is chosen shall, as we will see in section 3.4, depend on the importance the FA attaches to bank failure. To wrap up, Table 3.1 summarizes the players in our model and their choice variables.

We analyze the interaction between these players as a game: the bank, choosing its investment and monitoring, the CB that sets a LLR policy and the FA that decides on solvency assistance are all acting strategically. Other approaches, e.g. by Philippon and Schnabl (2012) and Bhattacharya and Nyborg (2010), employ mechanism design to tackle regulatory questions. However, these studies do not consider liquidity and

6 One could ask why we do not consider the DIF as the authority providing solvency assistance. In the United States this is common practice, with the Federal Deposit Insurance Corporation (FDIC) being in charge of bank resolution. However, in Europe this task often falls to the ministry of finance; this is the situation we are treating.

Table 3.1: Overview of players and their choices

Player	Choices
Bank	Investment & Monitoring
Central Bank	LLR policy
Fiscal Authority	Capital injection and its return structure

solvency at the same time. Rather, they focus on the problem of debt overhang that is more general in corporate finance, and a specific problem in banking. While they answer a very interesting question (are equity injections, asset purchases or debt guarantees optimal?), this method is not very suitable in capturing strategic interaction between banks and regulators.

Instead, our approach is closer to that of Repullo (2000, 2005) and Kahn and Santos (2005), in which the CB sets a certain threshold for the liquidity shock, beyond which it will not assist the bank anymore. To this game we add an authority (FA) that disposes over a solvency instrument. The FA can be seen as representative of the Treasury or Ministry of Finance, who address bank solvency problems. This resembles prompt corrective action as in Kocherlakota and Shim (2007) and Shim (2011). However, unlike in these analyses the FA is not maximizing social welfare. Instead, it is an independent authority with a mandate to resolve problems threatening financial stability[7].

Finally, we like to recall that we explicitly exclude both penalty rates (on liquidity) and ambiguity in our model. As we have noted in section 3.1, penalty rates have not been applied in recent financial crises, and certainly not in the most recent one. Furthermore, several authors have argued that penalty rates can increase moral hazard instead of reducing it, especially when banks are close to insolvency (Repullo, 2005; Castiglionesi and Wagner, 2011).

The doctrine of "constructive ambiguity" states that a bank should face some uncertainty about whether it will receive liquidity or not. This approach is analyzed

7 Although time inconsistency problems may be of concern to some, we have seen that several governments (e.g. the Dutch one) have been tough in providing bailout assistance.

by, among others, Freixas (1999), Goodhart and Huang (1999) and Cordella and Levy-Yeyati (2003), with contrasting results. While Freixas (1999) finds that ambiguity may have its merits in some cases (by reducing moral hazard), he also finds that it can lead to a Too-Big-to-Fail (TBTF) policy. Goodhart and Huang (1999) advocate a similar policy, but this is motivated by contagion concerns. Cordella and Levy-Yeyati (2003) conclude that *not* following an ambiguity policy can lead to an increase in bank charter value, compensating the possible moral hazard effect of having an LLR. Furthermore, in many financial crises (including the most recent one) ambiguity has not been applied. Every large or otherwise important financial institution has been assisted by either the central bank, fiscal authorities or both[8]. Therefore, we abstract from ambiguity. Let us now move to the formal specification of our model.

3.3 THE MODEL

We start this section with a brief summary of section 3.2. We consider an economy with risk-neutral agents and three dates: $t = 0, 1, 2$. In this economy, there is one systemically important bank that operates under limited liability and will choose how much to invest in risky assets and how much liquid reserves to keep. Additionally, the bank can choose to what extent it will monitor its risky investments, thereby affecting the return structure of these assets. Furthermore, the economy also contains two regulatory agencies: a Central Bank (CB) fulfilling the role of Lender of Last Resort (LLR) and a Fiscal Authority (FA) that, in case of a bank failure, has to decide on the failure resolution procedure. This authority disposes over a solvency instrument that can be used to increase the bank's capital. In return, the FA will ask either a fixed premium or an equity claim on bank value.

The bank starts at $t = 0$ with an exogenously given capital structure consisting of equity and deposits. We normalize the size of the bank to one[9], so we can denote the share of capital with k and the share of deposits with $1 - k$. As we have mentioned,

8 A notable exception being Lehman Brothers.

9 Since we have assumed that there is only one bank and thus bank failure is costly for society, we may abstract from letting bank size determine bank closure policy.

deposits are fully insured, which means they are riskless, and thus yield a return of one at $t = 2$. To abstract completely from deposit insurance issues, we assume that the bank pays no deposit insurance premium. Equity and deposits can be invested in a risky, illiquid asset or in liquid reserves. The share of reserves will be called l, which provides a riskless return of one on the fraction l. This implies that the riskless interest rate in our model is equal to zero. This definition leaves $1 - l$ to be invested in the risky asset. This asset provides a random gross return $\tilde{R}$ per unit of investment in period 2, with

$$\tilde{R} = \begin{cases} R(p) & \text{with probability } p \\ 0 & \text{with probability } 1-p, \end{cases}$$

where $p \in [0, 1]$ is the success probability of investment, which increase with the efforts of the bank to monitor this investment. The assumptions on $R(p)$ are summarized below.

Assumption 3.1: $R'(p) < 0, \quad R''(p) \leqslant 0, \quad R(p) \geqslant 1 \; \forall \; p \in [0, 1], \quad R(1) + R'(1) < 0.$

These return assumptions are also used by Boot and Thakor (1993), Cordella and Levy-Yeyati (2003) and Repullo (2005), and imply that there are decreasing returns to monitoring of investments. They also allow us to analyze moral hazard in a continuous manner. Expected return on investments $E(\tilde{R}) = pR(p)$ will be maximized at $\hat{p} \in (0, 1)$ where $\hat{p}$ is defined by $R(\hat{p}) + \hat{p}R'(\hat{p}) = 0$[10]. Furthermore, $E(\tilde{R})$ is greater than one, and investments are illiquid since they cannot be sold before $t = 2$. Note, finally, that the bank privately observes the realized return (0 or $R(p)$) on its investment at $t = 1$. This information is, however, not verifiable and can thus not be conditioned upon.

10 Note that, for $p = 0$, $\frac{dpR(p)}{dp} = R(0) > 0$ and, for $p = 1$, $R(1) + R'(1) < 0$. The second order condition for a maximum is $\frac{d^2pR(p)}{dp^2} = 2R'(p) + pR''(p) < 0$ for all $p > 0$. This suffices for an interior maximum at $\hat{p}$.

Given the above assumptions we can write bank value V at the end of period 2 as follows:

$$V = (R(p) - 1)(1 - l) + k. \tag{3.1}$$

This leads to the following expression for expected bank value:

$$p[(R(p) - 1)(1 - l) + k] + (1 - p)Max[l - (1 - k), 0]. \tag{3.2}$$

The maximization operator follows from the assumption that the bank operates under limited liability. However, as long as $\partial V/\partial l < 0$ (which holds in equilibrium in section 3.4) it will never be the case that $l > 1 - k$ and we can safely ignore the second term in expression (3.2). Furthermore, if the bank fails (with probability $1 - p$) it will be resolved by the DIF, as mentioned above.

3.3.1 *A liquidity shock*

At $t = 1$, a liquidity shock x occurs. This shock is independent from p and is uniformly distributed on the interval $(0, 1)$ with cumulative density $F(x) = x$ and probability density $f(x) = 1$. The size of the shock is public information when it occurs at $t = 1$. Taking into account that we have two regulatory agencies, we can distinguish three cases:

1. $x \leqslant \frac{l}{1-k} = \underline{x}$, in which the liquidity shock can be resolved using liquid reserves;
2. $\underline{x} < x \leqslant \overline{x}$, in which the bank is illiquid and will apply for emergency lending at the LLR. $\overline{x}$ is a threshold that is determined by the Central Bank, as described below; and
3. $\overline{x} < x$, in which the solvency of the bank is insufficient to warrant LLR borrowing and the fiscal authority will have to take a closure/continuation decision.

In case 1, the shock is small and the bank can repay the withdrawn deposits using its liquid reserves l. Note that we assume there is no interbank market; the bank's only liquidity comes from the amount of liquid reserves it has kept at $t = 0$[11].

In case 2, when $\underline{x} < x < \overline{x}$, the bank cannot finance the liquidity shortage by itself, so it has to apply for emergency liquidity from the Central Bank (CB) at an amount of $x(1-k) - l$. The CB will ask a repayment $R_{CB} = 1$ (we assume no penalty rate) at $t = 2$ and will only lend to solvent banks. This means it sets a threshold for x, called $\overline{x}$, above which it will not lend to the bank. We will elaborate on this in section 3.3.2.

In the third case, when $x > \overline{x}$, the bank cannot borrow from the CB. The bank will enter into a prompt corrective action programme by the fiscal authority (FA). The FA assists the bank by providing capital to increase the solvency position of the bank: its new capital ratio will become $k + k_{FA}$, where k_{FA} denotes the share that the FA contributes. As described in section 3.2, following bailout assistance the FA decides upon the conditions on which this capital will be provided. As we will explain in the next section, this decision depends on the importance the FA places on bank failure.

3.3.2 *Regulator's objectives*

As stated above, we have assumed the existence of two regulatory authorities: a CB and an FA. These authorities are given a mandate for financial stability by the government, who explicitly delegates this responsibility to these authorities. Instead of focusing on maximizing social welfare, both the CB and the FA will have a loss function that they should minimize. This reflects common arrangements in the institutional design of central banks, but also in that of financial supervisors and resolution authorities (Mayes, 2009).

The CB has two roles in our model: it is the Lender of Last Resort (LLR), but also the bank supervisor. In its role as LLR, it can observe the liquidity holdings l and needs $x(1-k) - l$ of a bank in distress, but not the amount of monitoring embodied in p. However, it does obtain a private signal $s_i \in \{s_0, s_i\}$ about the realized return on

11 This assumption can be justified since we are focusing on crisis management. In the financial crisis the interbank market nearly broke down (Allen et al., 2009; Diamond and Rajan, 2009). Massive intervention by central banks seemed to be the only way to get it going again.

the bank's investments at $t = 1$; the signal is independent from p and x. Since it provides information about bank solvency the signal can be used to decide upon liquidity assistance. Following Repullo (2005) the properties of this signal are as follows:

$$\Pr[s_0|R_0 = 0] = \Pr[s_1|R_1 = R(p)] = q \in [\frac{1}{2}, 1] \tag{3.3}$$

where $\Pr$ denotes a probability and q is the quality of supervisory information. The solvency signal tells the CB whether the return at $t = 2$ is low ($R_0 = 0$) or high ($R_1 = R(p)$), but does not transmit the actual value of the return $R(p)$. To gauge the informativeness of the signal, we can use Bayes' law:

$$\Pr[R_1|s_0] = \frac{\Pr[R_1]\Pr[s_0|R_1]}{\Pr[R_1]\Pr[s_0|R_1] + \Pr[R_0]\Pr[s_0|R_0]} = \frac{p(1-q)}{p(1-q) + (1-p)q} \tag{3.4}$$

$$\Pr[R_1|s_1] = \frac{\Pr[R_1]\Pr[s_1|R_1]}{\Pr[R_1]\Pr[s_1|R_1] + \Pr[R_0]\Pr[s_1|R_0]} = \frac{pq}{pq + (1-p)(1-q)}. \tag{3.5}$$

When $q = \frac{1}{2}$, the signal is uninformative since $\Pr[R_1|s_0] = \Pr[R_1|s_1] = p$, and when $q = 1$ the signal is completely informative since $\Pr[R_1|s_0] = 0$ and $\Pr[R_1|s_1] = 1$. We assume that $q > \frac{1}{2}$, which leads to $0 < \Pr[R_1|s_0] < p < \Pr[R_1|s_1] < 1$ for any $p < 1$. As Repullo (2005) notes, we can thus call s_0 and s_1 the bad and the good signal respectively.

In fulfilling its role of LLR, the CB will want to minimize the social cost of a bank's failure. This is reflected in the bankruptcy cost c, which may represent a breakdown of e.g. payment systems, interbank lending or the provision of credit for productive investment. The CB will therefore provide liquidity up to a certain threshold, which is based on the available information on liquidity and solvency (the signal). This follows from the generally accepted principle stated by Bagehot (1873): central banks should not lend to banks that are both illiquid and insolvent. In determining is liquidity provision threshold, the CB takes into account an expected cost of $\Pr[R_0|s_i][\alpha c + (x(1-k) - l)]$ when it supports the bank with emergency liquidity. When it does not support the bank, the CB incurs the certain loss αc. In these expressions, α is the weight the regulator attaches to the bankruptcy cost. This can be interpreted as the political or reputational cost to the central bank and is assumed to be greater than zero[12].

Comparing the two above expressions, $\Pr[R_0|s_i][\alpha c + (x(1-k) - l)] \leqslant \alpha c$, we can deduce two different thresholds for the CB at $t = 1$. These are denoted by $\overline{x}_i$, where i can be 0 or 1 and we use the fact that $\Pr[R_1|s_i] = 1 - \Pr[R_0|s_i]$:

$$x \leqslant \overline{x}_0 \equiv \frac{\frac{p(1-q)}{(1-p)q}\alpha c + l}{1-k} \qquad \text{for } s_0, \tag{3.6}$$

$$x \leqslant \overline{x}_1 \equiv \frac{\frac{pq}{(1-p)(1-q)}\alpha c + l}{1-k} \qquad \text{for } s_1. \tag{3.7}$$

Since we have assumed that $q > \frac{1}{2}$, it can be checked that $\overline{x}_0 < \overline{x}_1$. These thresholds mean that the bank will apply for an amount of $x(1-k) - l$ and the CB will only provide liquidity when (3.6) or (3.7) holds (depending on the realization of the solvency signal). Above these thresholds, the certain cost of a bank failure at $t = 1$ is greater than the expected cost of failure at $t = 2$.

In the case when $x > \overline{x}_i$, the FA will have to decide whether it closes the bank or provides solvency assistance. It has access to the same information as the CB, namely liquidity l and the solvency signal s_i. As stated above, the FA can assist the bank by increasing the bank's capital. The FA will provide this capital $k_{FA,i}$ to make sure that the CB alleviates the bank's liquidity problem completely; the size of the injection depends on the realization of s_i. Due to this capital injection (which may also be seen as a debt guarantee) the CB's new thresholds, which we call $\overline{\overline{x}}_i$, will thus become a function of $k_{FA,i}$:

$$x \leqslant \overline{\overline{x}}_0(k_{FA,0}) = \frac{\frac{p(1-q)}{(1-p)q}\alpha c + l}{1-(k+k_{FA,0})} \qquad \text{for } s_0, \tag{3.8}$$

$$x \leqslant \overline{\overline{x}}_1(k_{FA,1}) = \frac{\frac{pq}{(1-p)(1-q)}\alpha c + l}{1-(k+k_{FA,1})} \qquad \text{for } s_1. \tag{3.9}$$

12 $\alpha > 1$ in Kahn and Santos (2005), but Repullo (2000) assumes $\alpha < 1$ and Repullo (2005) assumes $\alpha = 1$. We will not yet make any assumptions other than $\alpha > 0$. The same holds for β in the case of the fiscal authority.

and $k_{FA,i}$ will be such that $x = \overline{\overline{x}}(k_{FA,i})$. This means that at $t = 1$, the FA injects capital such that the CB's threshold and the realization of the shock are equalized, such that the CB is willing to assist the bank with liquidity.

However, the FA will also have to weigh the benefits of injecting capital against the costs. When it assists the bank the FA demands a premium that depends on the weight it places on bankruptcy cost, which is denoted by β. The FA's premium is denoted by $r_{FA}(\beta)$, with properties $r'_{FA}(\beta) > 0$ and $r_{FA}(0) = 0$. Note that β is of similar nature as the CB's α, but it need not be equal to α. This reflects the political relation between the CB and the FA; they may have different responsibilities regarding financial stability. The net expected gains of providing capital depend on s_i and can be written as $\Pr[R_1|s_i]r_{FA}(\beta)k_{FA,i}(x) - \Pr[R_0|s_i](\beta c + k_{FA,i}(x))$. When it does not assist the bank, the FA will incur a certain cost βc. It follows that the maximum amount of capital that the FA is willing to provide will be determined by $\Pr[R_1|s_i]r_{FA}(\beta)k_{FA,i}(x) - \Pr[R_0|s_i](\beta c + k_{FA,i}(x)) \geqslant -\beta c$, or

$$k_{FA,0}(x) \leqslant \overline{k}_{FA,0} \equiv \frac{p(1-q)\beta c}{(1-p)q - p(1-q)r_{FA}(\beta)} \qquad \text{for } s_0, \tag{3.10}$$

$$k_{FA,1}(x) \leqslant \overline{k}_{FA,1} \equiv \frac{pq\beta c}{(1-p)(1-q) - pqr_{FA}(\beta)} \qquad \text{for } s_1. \tag{3.11}$$

Substituting the expressions in equations (3.10) and (3.11) into the new CB threshold $\overline{\overline{x}}(k_{FA,i})$, we arrive at maxima for this threshold:

$$\overline{\overline{x}}_0^{max} = \frac{\frac{p(1-q)}{(1-p)q}\alpha c + l}{1 - (k + \frac{p(1-q)\beta c}{(1-p)q - p(1-q)r_{FA}(\beta)})}, \tag{3.12}$$

$$\overline{\overline{x}}_1^{max} = \frac{\frac{pq}{(1-p)(1-q)}\alpha c + l}{1 - (k + \frac{pq\beta c}{(1-p)(1-q) - pqr_{FA}(\beta)})}. \tag{3.13}$$

As we can see, this depends positively on β (since $\frac{\partial \overline{k}_{FA,i}}{\partial \beta} > 0$), which can be interpreted as the weight the FA attaches to financial stability. Note, furthermore, that $\overline{k}_{FA,0}$ and $\overline{k}_{FA,1}$ are only positive for a β such that $(1-p)q - p(1-q)r_{FA}(\beta) > 0$ and $(1-p)(1-q) - pqr_{FA}(\beta) > 0$. This means it is only viable in case the FA attaches little importance to bank failure: β is low. It also leads to a subsidy on assistance: the expected gain for the FA is negative. Finally, when $\beta = 0$ the threshold will revert to $\overline{x}_i$ and the FA will take no action.

What will happen in case the FA cares very much about bank failure, i.e. in case β is high? We hypothesize that in this case the FA can demand an equity claim on the bank's value, in the form of a share g_i of V at $t = 2$ in case of success. Again, it will incur the bankruptcy cost βc and lose its investment $k_{FA,i}$ in case of failure. However, when it does not provide assistance, it will incur the cost βc with certainty. Furthermore, it again requires at least the premium $r_{FA}(\beta)$ on its investment. The trade-off the FA makes is the same as in the case with low β; however, instead of stipulating a maximum amount of capital it now sets a minimum repayment fraction g_i of V. This g_i is such that the FA at least breaks even, comparing the expected loss when it assists the bank to the certain loss under no assistance (conditional on the realization of s_i):

$$g_0 \geqslant \frac{1}{V}\left(\frac{r_{FA}(\beta)p(1-q)-(1-p)q}{p(1-q)}k_{FA}(x)+\beta c\right), \tag{3.14}$$

$$g_1 \geqslant \frac{1}{V}\left(\frac{r_{FA}(\beta)pq-(1-p)(1-q)}{pq}k_{FA}(x)+\beta c\right). \tag{3.15}$$

We will assume that this will hold with equality in equilibrium, as the FA will just need to break even to be willing to provide capital. Furthermore, as we have assumed β is large, $r_{FA}(\beta)p(1-q)-(1-p)q > 0$, $r_{FA}(\beta)pq-(1-p)(1-q) > 0$ and thus $g_i > 0$.

The first possibility of government assistance or bailout, where the FA injects debt, is a stylized representation of the situation in which a bank is recapitalized or provided with guarantees on its borrowing, at a certain price that is set ex ante. The second possibility, with a required period 2 return of g_i, can be seen as the government providing funds with a preferred equity claim, which is determined ex post. In the extreme ($g_i = 1$) this will lead to a nationalization of the bank. Note that this latter case is essentially the same as having solely a CB as LLR: in both cases, the bank will get nothing when $x > \overline{x}_i$.

These measures have been used extensively in crisis management during the last 2 years. Of course, these measures have not been free for banks: regulators have set a premium on the rates to be paid for access to these facilities, as the government has taken over part of the risk from the bank. This premium is, for instance, represented by g_i, which contains the abovementioned r_{FA}. Bailout assistance thus comes at a cost for the bank owner.

A final remark on central bank and government budgets is in order. We assume that the central bank has no explicit budget constraint, as it can create (virtually) unlimited liquidity to cope with liquidity shocks. However, the FA (or government) cannot do this. If it would have to raise funds ex ante through taxes, this would reduce productivity since banks are taxed. As we analyze a partial equilibrium situation, the funding mechanism is not taken into account. Instead, we assume the existence of a capital market on which the FA, being a creditworthy government, can borrow at the risk-free rate. In other words: the funding structure of the FA is exogenous.

3.3.3 *The bank's objective*

Taking the liquidity shock and the regulatory system into account, the bank owner will maximize total bank value at $t = 2$. The choice variables for the bank owner are the effort put into monitoring, embodied in the probability of success p, and the amount of investment $1 - l$. The probability of success, which increases with monitoring effort at $t = 0$, can be interpreted as the inverse of the amount of risk taken.

Using the properties of the liquidity shock, the solvency signal and the aforementioned conditions $\overline{x}$ and g set by the regulatory authorities, we can refine the bank's objective function. We assume that there is no time discounting. The bank owner will maximize its $t = 2$ payoff, denoted by Π_2, under different regimes and different realizations of the shock x and the signal s_i:

$$\Pi_2 = \begin{cases} \int_0^{\underline{x}} pVdF(x) & \text{without any safety net,} \\ \\ (1-q)\int_0^{\overline{x}_0} pVdF(x) + q\int_1^{\overline{x}_1} pVdF(x) & \text{when CB acts as LLR,} \\ \\ (1-q)\int_0^{\overline{\overline{x}}_0^{max}} pVdF(x) + q\int_0^{\overline{\overline{x}}_1^{max}} pVdF(x) & \\ -(1-q)\int_{\overline{x}_0}^{\overline{\overline{x}}_0^{max}} pr_{FA}(\beta)k_{FA,0}(x)dF(x) & \text{when FA claims debt,} \\ -q\int_{\overline{x}_1}^{\overline{\overline{x}}_1^{max}} pr_{FA}(\beta)k_{FA,1}(x)dF(x) & \\ \\ pV-(1-q)\int_{\overline{x}_0}^{1} pg_0VdF(x) - q\int_{\overline{x}_1}^{1} pg_1VdF(x) & \text{when FA claims equity.} \end{cases}$$

We can see that expected bank value is not only varying with p and l, but also with $\overline{x}$, $\overline{\overline{x}}$, k_{FA} and g. This indicates that it depends on the choices made by the bank owner as well as those made by the regulators. In the next section we will characterize this interdependence.

3.4 LIQUIDITY OR LIQUIDATION

To summarize the previous sections, we can systematically go through the sequence of events. We let the bank simultaneously choose its risk p (determined by its monitoring effort) and its portfolio of risky investments $1-l$ at $t = 0$, taking into account the possibility of liquidity shocks at $t = 1$ and responses by the CB and the FA. At $t = 1$, the liquidity shock realizes and it is observable. If $x \leqslant \underline{x}$, the bank pays depositors out of its liquidity reserves. If $\underline{x} < x \leqslant \overline{x}$, the bank applies for liquidity and the CB will provide it. Finally, if $x > \overline{x}$, the CB is not willing to provide liquidity and the FA will take action, leading to either a premium repayment by or an equity claim on the bank. Finally, at $t = 2$ returns on $1-l$ realize and assistance has to be repaid.

3.4.1 *Social welfare maximization*

As a benchmark, we first analyze the socially efficient solution to the problem of choosing optimal investment and risk taking in our economy with one bank. In this case, a social planner will choose risk, investment and the regulatory instruments such that the social value of bank investments is maximized. This means that these choices also incorporate the externalities from bank failure; this assumption will not hold in a private bank setting.

We assume that for society as a whole, liquidity can be obtained at zero cost and is in essence just a transfer of funds from $t = 2$ to $t = 1$ (when the investment has positive NPV). Therefore, liquidity assistance will always be provided when it is necessary[13]. The gains to society are the total profit on bank investments at $t = 2$ minus the potential bank failure costs. These costs are comprised of DIF costs and bankruptcy costs c, and realize when the investment fails and the DIF has to pay depositors $(1-k)-l$. The problem to solve is thus:

$$\max_{p,l} \quad pV - pk - (1-p)((1-k) - l + c). \tag{3.16}$$

The first order conditions for (3.16) are:

$$R(p^{sw}) + p^{sw}R'(p^{sw}) = -\frac{c-k}{1-l^{sw}} \tag{3.17}$$

$$1 - p^{sw}R(p^{sw}) = 0, \tag{3.18}$$

representing marginal benefits and costs of monitoring and liquidity, respectively. We assume that the costs of failure are larger than the value of capital, so $c - k > 0$. Since liquidity is costless for society as a whole, it should be optimal to invest all available funds into the productive, risky asset and keep no reserves. This also means that the two first order conditions do not lead to an interior solution, but to a corner solution with zero liquidity:

13 This assumption serves to restrict our analysis to the game between banks and regulators, without considering aggregate liquidity problems. For analyses of this nature, see i.e. Holmstrom and Tirole (1998), Diamond and Rajan (2005) or Allen et al. (2009)

Proposition 3.1: *it is socially optimal to invest all of the bank's funds in the risky, productive asset. As a consequence, monitoring effort will be chosen to maximize the expected return on investment.*

Proof: by contradiction. Suppose that condition (3.18) holds, which means that p^{sw} is such that $E(\tilde{R}) = 1$. We have assumed that $E(\tilde{R}) > 1$ at its optimum $\hat{p}$ (when $R(\hat{p}) + \hat{p}R'(\hat{p}) = 0$) and that $\frac{\partial^2 E(\tilde{R})}{\partial p^2} < 0 \ \forall \ p$, so it must hold that $p^{sw} < \hat{p}$. However, this also means that $R(p^{sw}) + p^{sw}R'(p^{sw}) > 0$, which contradicts condition (3.17). Therefore, p has to increase toward $\hat{p}$ until condition (3.17) holds (with $p^{sw} > \hat{p}$ for $k < c$). This means that condition (3.18) no longer holds: $1 - p^{sw}R(p^{sw}) < 0$ and thus $l^{sw} = 0$. ■

The intuition behind this is that the marginal benefit of liquidity is less than its opportunity cost (expected return on investment) and thus no liquid reserves will be held. It is thus socially optimal to set $l^{sw} = 0$ and invest all funds in the risky asset; with this knowledge, monitoring effort (and thus p^{sw}) is chosen to maximize the expected return on these investments. This allocation maximizes the social value of banking, and reflects Bagehot's most important notion: solvent banks will always receive liquidity. As monitoring is chosen to maximize expected return, which is positive, liquidity provision is always warranted. Therefore, it is optimal for the social planner to solely focus on the bank's solvency.

This follows the reasoning in, among others, Allen et al. (2009), who find that it is optimal to invest in risky or productive assets as long as there are no aggregate liquidity problems and idiosyncratic liquidity risks are covered. Since we assume that obtaining liquidity is costly for society (as long as the investment is ex ante profitable) it is optimal to invest nothing in liquid assets. Note that this is a special, partial equilibrium case of the analysis in Allen et al. (2009). More recently, Malherbe (2012) presents a model in which there is abundant liquidity, and cash liquidity holdings are only necessary to cope with an inability to trade in the interbank market (in fact, they even exacerbate this problem). In our model there is no adverse selection in society as a whole and liquidity is freely available, so it is not optimal to hold any liquidity.

3.4.2 *Bank optimization without regulation*

Let us now consider the case of a private bank choosing an optimal portfolio, and analyze whether it reaches the socially efficient allocation. We assume that there are no regulatory authorities, such as a Lender of Last Resort or a fiscal authority, which may provide assistance. There is also no possibility to go to the interbank market, as mentioned above. The bank thus has to cope with liquidity shocks on its own, which means that the bank fails if the sudden demand for liquidity is larger than the bank's liquid assets. In case of failure, the returns at $t = 2$ are zero, since effectively $g = 1$ when there is no FA. The bank's expected value is thus equal to

$$\int_0^{\underline{x}} pVdf(x) \tag{3.19}$$

and the bank maximizes this by choosing investment $1 - l$ and monitoring p, which leads us to the following result.

Proposition 3.2: *The bank monitors less than is socially optimal (it engages in moral hazard), but also invests less in productive assets than is optimal (it keeps more liquidity). An increase in capital can alleviate the moral hazard problem, but also leads to less productive investment.*

Proof: see appendix ■.

The bank owner thus generates too little productive investment compared to the socially efficient case, and takes too much risk while doing so. The investment decision follows from the assumption that there is no safety net in the form of a central bank able to provide emergency liquidity; the bank has to reserve part of its funds to cope with liquidity shocks. As it has to keep more liquidity on its balance sheet, the bank tries to make up for the foregone investment returns by taking more risk. This means the bank owner "gambles" for a higher return in case of success; in case of failure, he will only lose his capital k because of limited liability. This is harmful to social welfare.

3.4.3 *The Central Bank as the Lender of Last Resort*

Conventionally, if liquidity problems cannot be dealt with through the interbank market a Central Bank (CB) can step in as the Lender of Last Resort (LLR). The CB will provide liquidity as long as it deems a bank solvent, allowing it to invest more into the productive asset and thereby adding to social welfare.

The bank owner then chooses risk-taking and the amount of investment in this new situation by setting p and l, with equilibrium values p^{ℓ} and l^{ℓ} (where the superscript ℓ denotes that we are dealing with the possibility of liquidity provision). As in Repullo (2005) and Kahn and Santos (2005), bank and CB play a simultaneous Bayesian Nash game in the determination of p and $\overline{x}_i$. In this game, the CB can only observe the choice of l (from the bank's balance sheet) when it has to make a liquidity provision decision at $t = 1$; this observation of l is not verifiable. The CB does not know the choice of p at this moment; it only receives the solvency signal s_i[14]. However, the CB can form a belief about p^{ℓ} through its knowledge of l and k, and the realization of the signal s_i. The thresholds can thus be written as

$$\overline{x}_0 = \frac{p^{\ell}(1-q)}{(1-p^{\ell})q}\frac{\alpha c}{1-k} + \frac{l}{1-k}, \tag{3.20}$$

$$\overline{x}_1 = \frac{p^{\ell}q}{(1-p^{\ell})(1-q)}\frac{\alpha c}{1-k} + \frac{l}{1-k}, \tag{3.21}$$

with equilibrium value $\overline{x}_i^{l} = \overline{x}_i(p^{\ell}, l^{\ell})$. This threshold shows that the CB only faces downside risk; the bank gets the upside. We can also see that the threshold depends only on the bank's actual choice of l; it doesn't change directly with the actual choice of p. Instead, it is determined by the realization of the signal s_i and by p^{ℓ}, the equilibrium value of p.

Furthermore, if $x > \overline{x}_i^{\ell}$ the bank finds itself in a crisis situation and it will be taken over completely by the fiscal authority. The depositors will be compensated by the DIF, and the remaining parts of the bank will be sold by the FA at $t = 2$. The bank

14 One could say that if the CB knows the form of the function $R(\cdot)$, it can infer the choice of p perfectly ex post. However, we assume that the CB does not exactly know what the monitoring technology of the bank looks like. Additionally, it is often not possible to contract upon returns that are not verifiable.

owner will thus get a zero return when $x > \overline{x}_i^\ell$; we will relax this assumption in the next section.

At $t = 0$, the bank will take all this into account while choosing p and l. Its new objective is thus

$$\max_{p,l}(1-q)\int_0^{\overline{x}_0^\ell} pVdF(x) + q\int_0^{\overline{x}_1^\ell} pVdF(x) \tag{3.22}$$

taking into account the equilibrium decision by the CB. The following result obtains.

Proposition 3.3: *With a central bank acting as the lender of last resort the bank engages in moral hazard, but also invests more in the productive asset. An increase in capital can counteract both these effects.*

Proof: see appendix ■.

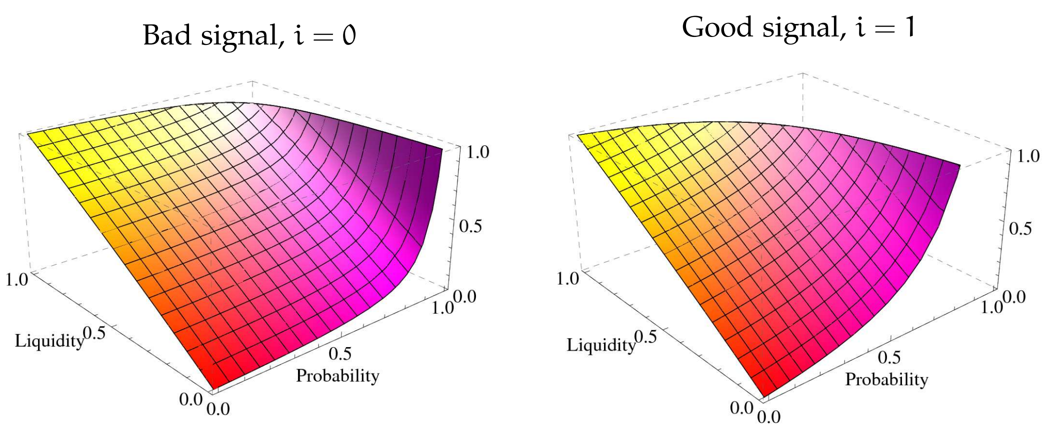
The bank thus invests more in productive assets than in the situation without a liquidity provider: a positive development facilitated by the CB acting as an LLR. However, it also takes more risks when doing so, which is worse from a social point of view. This may reflect a moral hazard effect caused by the introduction of a safety net: since there is a Lender of Last Resort, the bank takes more risk.

To illustrate this phenomenon, we have calibrated our model using reasonable parameter values. We have specified the returns as a concave decreasing function of p, namely $R(p) = 3 - 2p^2$ (satisfying the assumptions from section 3.3), and the cost of bankruptcy is set to 0.10 or 10% of the bank's balance sheet (Repullo, 2005). α is set to 1 (Cordella and Levy-Yeyati, 2003) and the capital ratio k is assumed to be at the minimum Basel II requirement, which is 8% of risk weighted assets. We assume that the risky asset gets a 100% weight. We set $q = 0.7$ to emphasize the difference between $\overline{x}_0$ and $\overline{x}_1$.

Figure 3.2 shows that investment and the critical shock threshold are indeed negatively related, as an increase in investment means a decrease in liquidity buffers. We also see that the probability of success and the solvency threshold are positively related. This means that an increase in investment should be met with an increase in its success probability to keep the threshold at the same level. As the right-hand side of the figure shows this relationship is stronger when the solvency signal is good. At a given level of p, the threshold is higher when the signal's realization is s_1 than when it is s_0. In other words, the CB is more willing to assist a solvent bank.

The bank will thus face a trade-off between investment and risk-taking if it wants to induce the CB to set the optimal solvency threshold, given the supervisory signal. In equilibrium this leads to a lower l, but also a lower p, compared to the situation without an LLR: there is more productive investment (and less liquidity), but this goes with increased moral hazard.

Figure 3.2: The optimal solvency threshold $\overline{x}_i$



In section 3.2 we have stated plausible reasons to abstract from penalty rates and the "constructive ambiguity" principle[15].Instead, we focus on a situation in which the regulator will bail out the bank by injecting capital and, at the same time, determines what cost will be attached to this assistance.

15 When we would have a penalty rate ($R_{CB} > 1$) the bank would choose even lower p and higher l, as in Repullo (2005). Proof available upon request.

3.4.4 *The possibility of bailout*

After analyzing the case where a bank goes simply bankrupt when a large shock occurs (i.e. when $x > \overline{x}_i$), we will now have the Fiscal Authority assist the bank in cases of severe distress. As mentioned above, the FA injects capital $k_{FA,i}$ into the bank to improve its solvency. The repayment of this capital can be structured in two different ways: the FA either sets an ex ante premium that has to be repaid by the bank, or it will demand a share g_i in the bank's final value. These options reflect senior debt and preferred equity, respectively.

3.4.4.1 *Senior debt assistance*

We assume that the fiscal authority gets supervisory information from the central bank. Therefore, the bank and the FA, just as the bank and the CB, play a simultaneous Bayesian Nash game. This means that the FA can only condition $k_{FA,i}$ on l and the realization of x and s_i, but not on p (only on its equilibrium value p^d). We will assume additionally that the CB and the FA observe each other's actions, but take them for granted. There is no ex ante cooperation between the CB and the FA apart from information sharing, as the FA also observes the signal s_i. The only way in which the FA can influence the CB's actions is by injecting capital $k_{FA,i}$. This makes the bank more solvent from the CB's viewpoint, thereby increasing the CB's solvency threshold to $\overline{\overline{x}}_i$. The FA will then require the bank to repay this assistance at a premium $r_{FA}(\beta)$, where β is relatively low. The new equilibrium CB threshold $\overline{\overline{x}}_i$ can be written as follows:

$$x \leqslant \overline{\overline{x}}_0 \equiv \frac{\frac{p^d(1-q}{(1-p^d)q}\alpha c + l}{1-(k+k_{FA,0}(x,p^d,l))}, \tag{3.23}$$

$$x \leqslant \overline{\overline{x}}_1 \equiv \frac{\frac{p^d q}{(1-p^d)(1-q)}\alpha c + l}{1-(k+k_{FA,1}(x,p^d,l))}. \tag{3.24}$$

As the FA only injects capital when the shock x has been observed, it can provide just enough capital to make $x = \overline{\overline{x}}_i$ hold:

$$k_{FA,0}(x) = (1-k) - \left(1 - \frac{\overline{x}_0}{x}\right), \tag{3.25}$$

$$k_{FA,1}(x) = (1-k) - \left(1 - \frac{\overline{x}_0}{x}\right). \tag{3.26}$$

As we have seen in section 3.3.2, when β is low the FA will not provide $k_{FA,i}$ larger than $\overline{k}_{FA,i}$. Therefore, the new CB threshold $\overline{\overline{x}}_i$ will not be higher than $\overline{\overline{x}}max_i$.

These reaction functions of the regulators are known by the bank ex ante, and it will take them into account when determining p^d and l^d. The bank's objective is thus

$$\begin{aligned} \max_{p,l} \quad & (1-q)\int_0^{\overline{\overline{x}}_0^{max}} pVdF(x) + q\int_0^{\overline{\overline{x}}_1^{max}} pVdF(x) \\ & -(1-q)\int_{\overline{x}_0}^{\overline{\overline{x}}_0^{max}} pr_{FA}(\beta)k_{FA,0}(x)dF(x) \\ & -q\int_{\overline{x}_1}^{\overline{\overline{x}}_1^{max}} pr_{FA}(\beta)k_{FA,1}(x)dF(x). \end{aligned} \tag{3.27}$$

The bank again maximizes its value at $t = 2$, taking into account that it will have to pay a premium on capital assistance when the shock is higher than $\overline{x}_i$. This form of assistance can have effects on both monitoring and risk taking. To see this, observe that this case is in fact a generalization of the case in section 3.4.3: when $\beta = 0$, there is no FA activity and we are back in the situation with only a CB. By analyzing the effects of an increase in β at $\beta = 0$, we can determine the effect of having FA assistance in the form of debt. We obtain the following result.

Proposition 3.4: *having a Fiscal Authority provide solvency assistance in the form of debt capital, additional to a CB providing liquidity, has two effects. It leads to less moral hazard and more productive investment, compared to the case with only a CB as a liquidity provider.*

Proof: see appendix ■.

This means that the FA policy of injecting capital to increase the solvency threshold has positive effects: as β increases above zero, which means the FA will take action, we see that both investment and monitoring increase (p increases and l decreases). In other words, this policy decreases moral hazard, while it also promotes socially productive investment.The intuition behind this is straightforward: as long as $r_{FA}(\beta)k_{FA}(x) < (R(p)-1)(1-l)$ the bank gains from assistance by the FA. Therefore, it pays to increase the probability of success p and decrease liquid reserves l; both actions increase the part of bank value that the bank owner can appropriate at $t = 2$.

However, it is common practice to assist banks by providing equity instead of debt capital; it is thus also useful to assess what happens when the FA claims an equity stake instead of a fixed premium on its debt assistance. We will address this situation in the next section.

3.4.4.2 *Equity assistance*

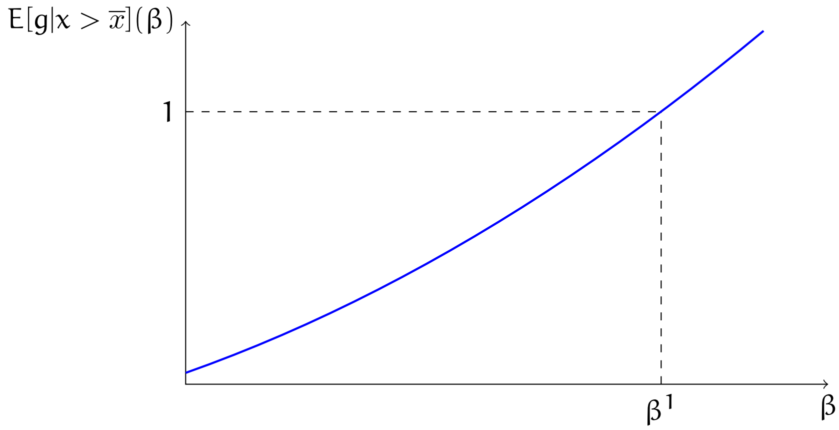
As before, the CB will be willing to provide liquidity as long as x does not exceed $\overline{x}_i$. Above this threshold, the FA will again inject $k_{FA_i}(x)$ into the bank. However, it now stipulates its minimum required return as a share in the bank's value at $t = 2$; this is denoted by g_i.

The bank again chooses risk-taking and the amount of investment in this new situation by setting p and l, with equilibrium values p^e and l^e. The e indicates that we have added the possibility providing equity capital to the bank. As described before, g_i is determined at $t = 1$ by the following equations, where we can see it depends on the bank's actual choice of l, but only on its *equilibrium* choice of p, which is p^e:

$$g_0 \geqslant \frac{\frac{r_{FA}(\beta)(1-q)p^e-(1-p^e)q}{p^e(1-q)}k_{FA_0}(x) + \beta c}{V(p^e, l)}, \tag{3.28}$$

$$g_1 \geqslant \frac{\frac{r_{FA}(\beta)(qp^e-(1-p^e)(1-q)}{p^e q)}k_{FA_1}(x) + \beta c}{V(p^e, l)}. \tag{3.29}$$

Figure 3.3: The FA's expected required return $E[g_i|x > \overline{x}](\beta)$



Note: the FA will nationalize the bank at $E[g_i|x > \overline{x}](\beta^1) = 1$.

These will hold with equality in equilibrium, as the FA only needs to break even in expectation. For the bank, this g_i will be a function of the expectation of x, conditional on $x > \overline{x}_i$, where $\overline{x}_i$ is determined in a similar manner as in section 3.4.3 and $\overline{x}_i^e$ is its equilibrium value. The expected value of g_i can be written as:

$$E[g_0|x > \overline{x}_0] = \int_{\overline{x}_0^e}^{1} \frac{\frac{r_{FA}(\beta)(1-q)p^e-(1-p^e)q}{p^e(1-q)} k_{FA_0}(x) + \beta c}{V(p^e, l)} dF(x), \tag{3.30}$$

$$E[g_1|x > \overline{x}_1] = \int_{\overline{x}_1^e}^{1} \frac{\frac{r_{FA}(\beta)(qp^e-(1-p^e)(1-q)}{p^e q)} k_{FA_1}(x) + \beta c}{V(p^e, l)} dF(x). \tag{3.31}$$

Examining the properties of $E[g_i|x > \overline{x}]$ leads us to the following useful result, illustrated in Figure 3.3. Note that this only depicts the shape of the functions; it does not necessarily state the relative sizes of $E[g_0|x > \overline{x}_0]$ and $E[g_1|x > \overline{x}_1]$.

Lemma 3.1: *There exists a level of* β, *called* β^1, *for which* $E[g_i|x > \overline{x}] \geqslant 1$ *for* $i = 0, 1$. *At or above* β^1 *the bank is nationalized in expectation, as the FA appropriates all of the bank's value at* $t = 2$.

Proof: see appendix ■.

To analyze what happens to monitoring and investment when we allow for a bailout in the form of equity assistance, we can again employ comparative statics on β. Since the introduction of a bailout possibility means that $E[g_i|x > \overline{x}_i] < 1$ (as opposed to $E[g_i|x > \overline{x}_i] = 1$, were the bank is nationalized completely), our analysis should focus on the effect of this change: this consists of a decrease in β from β^1.

The bank takes into account that it will now have to pay a premium on capital assistance when x exceeds $\overline{x}$. Its new objective is thus as follows:

$$\max_{p,l} \quad pV - (1-q)\int_{\overline{x}_0}^{1} pVg_0\, dF(x) - q\int_{\overline{x}_1}^{1} pVg_1\, dF(x). \tag{3.32}$$

A quick look at this objective reveals that the case of $\beta = \beta^1$ is the same as the case in which there is only a CB. Thus, adding the possibility of equity assistance is a generalization: section 3.4.3 represents a special case in which $E[g_i|x > \overline{x}_i] = 1$. Solving the bank's objective and applying Lemma 1, leads to the following result:

Proposition 3.5: *having a Fiscal Authority providing solvency assistance in the form of equity capital, additional to a CB providing liquidity, has two effects. It reduces the bank's moral hazard while decreasing productive investment, compared to the case with only a CB providing liquidity.*

Proof: see appendix ■.

Although the payoff structure is different from debt assistance, the bank has similar incentives in this setup with equity assistance. It will still want to increase the probability of success, as it now gains a positive amount when $x > \overline{x}_i$. As it will also be assisted under a broader range of shock realizations, the bank needs lower liquidity buffers and can thus invest more in productive assets.

Our conclusion from this analysis is that the introduction of an FA that, instead of completely nationalizing the bank, can claim part of bank value at $t = 2$ (exemplified by decreasing β below β^1) has positive effects. The probability of success p and productive investment $1 - l$ both increase. An FA that will not completely nationalize the bank ($g = 1$), but leaves something from the bank owner, can thus induce the banker to invest more in the risky asset and monitor it better. In the next section, we summarize the different liquidity and bailout possibilities we have considered above.

3.4.5 *Wrapping up*

Table 3.2 summarizes the different situations analyzed in the previous sections. As expected, no regulation or safety net will cause the bank to gamble and hoard too much liquidity. A central bank can improve on this, but the moral hazard problem will be more severe. When the government or fiscal authority does not have much concern for bank failure (low β), it injects capital into the bank in the form of a debt contract. This will alleviate the moral hazard problem and increase productive investment. A fiscal authority that attaches much value to bank failure costs (high β), however, will demand an equity claim on the bank's value in case capital has to be provided.This also alleviates the moral hazard problem and leads to more productive investment. The difference between these two situation lies in the mandate of the FA towards financial stability: a regulator much concerned with financial stability will want to control the bank, and thus has to demand an equity stake. A regulator that is less concerned about bank failure will be able to provide assistance in the form of a debt contract, which also has a positive effect on investment.

Table 3.2: Effects of different regimes on monitoring and investment, relative to social optimum

	Monitoring	Investment
No regulation	-	-
CB as LLR	-	+
FA owns debt	+	+
FA owns equity	+	+

Regulatory authorities that attach much importance to financial stability (as is often the case in the period after a financial crisis) can thus provide the right incentives to the banker. As it provides solvency assistance that is costly to the banker (either in debt or equity form), the banker invests more and monitors this investment better. This seems to be at least partly realistic: the nationalization, bailout and guarantee efforts by governments in the crisis of 2008-2009 have led banks to mitigate their risk taking. On the other hand, their investments did not markedly increase; a development that deserves further investigation.

3.5 CONCLUSION

The recent financial crisis has provoked governments and central banks to supply unusually large amounts of capital and liquidity to banks. Regard for systemic stability is the main motivation for providing this support to the financial system. However, the risk for financial stability (ultimately leading to the financial crisis) has arisen because of excessive risk taking by individual institutions that were central to the system. Since they thus posed a risk for the financial system as a whole, regulators had no choice but to prevent them from failing.

Because of the enormous costs that are associated with bank failure, but also with its prevention, it is necessary to complement Bagehot (1873)'s principle for an LLR with new measures. In our analytical model, we have thus simultaneously allowed for liquidity provision (by a central bank) and capital assistance (by a fiscal authority) to examine how they interact with a bank facing a crisis.

We have assessed this interaction for an individual bank suffering from liquidity shocks, with which it can only cope by keeping liquid reserves. There is no interbank market in our model, reflecting a crisis situation in which the interbank market does not function well. We find that without any safety net a bank hoards too much liquid assets and takes too much risk, compared to the socially efficient situation.

The introduction of a liquidity provider in the form of a Central Bank (CB) should alleviate this problem (as suggested by Bagehot (1873)). This CB has no information other than the bank's investment level. It cannot observe the bank's choice of risk ex ante and can thus not condition its Lender of Last Resort (LLR) policy upon this information. It does, however, receive an imperfect supervisory signal that provides partial information about bank solvency. We find that a CB as LLR indeed induces a higher investment level. However, the introduction of a safety net also increases moral hazard as found by Freixas (1999).

To improve the situation, we introduce a second regulator in the form of a fiscal authority (FA) that is responsible for the bank closure decision. It can also decide to give the bank a capital injection if it deems the bank solvent. This FA has the same information as the CB. We find that when the FA has little concern for financial stability, capital provision in return for a fixed premium is optimal. This mitigates the moral hazard problem and causes the bank to invest more in productive assets. However, when the FA is much concerned about bank failure, it will demand an equity claim on bank value. This can also alleviate the moral hazard problem and increase investment. Thus, both manners of solvency assistance provide the right incentives to the bank.

To complement Bagehot's principle of the Lender of Last Resort we introduced an additional authority that can improve bank solvency. Giving this authority substantial responsibility for financial stability is not a completely satisfactory solution for curbing excessive risk taking. This result is partly in line with the situation after the 2008/2009 crisis: although banks took less risk, they also provided less credit to the economy (an observation that goes against our results). Furthermore, relative effects of CB and government policies are also likely to play a role: central banks continued to provide liquidity to stimulate lending. To support this liquidity provision governments had to improve bank solvency. Strict terms on this solvency assistance required banks to reduce risk, while they also hoarded more liquid reserves instead of investing more. This observation merits future research, which should perhaps also take into account market developments.

3.A APPENDIX: PROOFS

Proof of Proposition 3.2:

The bank simultaneously chooses optimal values $p = p^n$ and $l = l^n$ to maximize its objective in equation (3.19). The choice of p^n is given by the following first order condition (FOC):

$$R(p^n) + p^n R'(p^n) = 1 - \frac{k}{1 - l^n}, \tag{3.A.1}$$

which holds since $l > 0$: if $l = 0$, $\underline{x} = 0$ and the bank would always fail. The bank would thus choose $l^n > 0$ to receive a positive payoff at $t = 2$. Next, for l^n the following FOC holds:

$$l^n = \frac{1}{2}\left[1 + \frac{k}{R(p^n) - 1}\right] \tag{3.A.2}$$

where we have used $\frac{\partial \underline{x}}{\partial(1-l)} = -\frac{1}{1-k}$. Under the assumptions on $R(p)$ these FOCs also fulfill the second order conditions for a maximum.

We can deduce from equations (3.A.1) and (3.A.2) that the bank takes more risk than is desirable from a social perspective. This follows from our assumption that the bank invests with leverage (i.e. $1 - k > l > 0$), which means $1 - l^n > k$ and thus $R(p^n) + p^n R'(p^n) > 0$. As $R(p^n) + p^n R'(p^n)$ is decreasing in p, we see that $p^n < p^{sw}$. Furthermore, we can state that $l^n > 0 = l^{sw}$, which follows from assuming that $k > 0$ and $R(p^n) > 1$ (otherwise it would not be profitable to invest in the risky asset).

$$l^n - l^{sw} = \frac{1}{2}\left[1 + \frac{k}{R(p^n) - 1)}\right] > 0. \tag{3.A.3}$$

Finally, the capital effect can be deduced from equations (3.A.1) and (3.A.2): $\frac{\partial p^n}{\partial k} > 0$ and $\frac{\partial l^n}{\partial k} > 0$ at $R(p^n) > 1$, a condition that should hold in equilibrium.

Proof of Proposition 3.3:

The corresponding FOC w.r.t. p and l are:

$$R(p^\ell) + p^\ell R'(p^\ell) = 1 - \frac{k}{1-l^\ell} \tag{3.A.4}$$

$$l^\ell = \frac{1}{2}\left[1 + \frac{k}{R(p^\ell)-1} - \alpha c((1-q)\frac{p^\ell(1-q)}{(1-p^\ell)q} + q\frac{p^\ell q}{(1-p^\ell)(1-q)})\right] \tag{3.A.5}$$

where we can see that p^ℓ and l^ℓ are determined in a similar way as p^n and l^n. However, we also see that $l^n \neq l^\ell$ when $\alpha > 0$, which means that $\overline{x}_1^l > \overline{x}_0^l > \underline{x}$. To determine the relative size of l^n and l^ℓ, we note that when $\alpha = 0$ the CB will never intervene. This is equivalent to the situation without a safety net. It is thus straightforward to perform comparative statics regarding α by taking the total derivative of l^ℓ w.r.t. α (note that $\frac{\partial p}{\partial \alpha} = 0$):

$$\frac{dl^\ell}{d\alpha} = \frac{\partial l^\ell}{\partial \alpha} + \frac{\partial l^\ell}{\partial p^\ell}\underbrace{\frac{\partial p^\ell}{\partial \alpha}}_{=0} = -\frac{c}{2}((1-q)\frac{p^\ell(1-q)}{(1-p^\ell)q} + q\frac{p^\ell q}{(1-p^\ell)(1-q)}) < 0. \tag{3.A.6}$$

This expression indicates that l^ℓ decreases when α increases (a CB is set up), which means that $l^\ell < l^n$, and thus that $1 - l^\ell > 1 - l^n$.

To compare p^ℓ with p^n, we again consider what happens as $\alpha \to 0$ by performing comparative statics w.r.t α:

$$\begin{aligned}\frac{dp^\ell}{d\alpha} &= \underbrace{\frac{\partial p^\ell}{\partial \alpha}}_{=0} + \frac{\partial p^\ell}{\partial l^\ell}\frac{\partial l^\ell}{\partial \alpha} \\ &= \left(\frac{-k/(1-l)^2}{2R'(p)+pR''(p)}\right)\left(\frac{-c}{2}((1-q)\frac{p^\ell(1-q)}{(1-p^\ell)q} + q\frac{p^\ell q}{(1-p^\ell)(1-q)})\right) \\ &< 0 \end{aligned} \tag{3.A.7}$$

where the inequality holds because of the assumptions on $R(p)$. As the effect of α on p is negative, we must conclude that $p^\ell < p^n$ when $\alpha > 0$.

Proof of Proposition 3.4:

Equation (3.27) is maximized according to the following FOC, where we have used $f(x) = 1$ and we have not explicitly written out all the partial derivatives to save space:

$$\begin{aligned}
FOC_p^d := \quad & \left((1-q)\overline{\overline{x}}_0^{max} + q\overline{\overline{x}}_1^{max}\right)\left(V + p\frac{\partial V}{\partial p}\right) \\
& - pr_{FA}(\beta)\left((1-q)\int_{\overline{x}}^{\overline{\overline{x}}_0^{max}} k_{FA_0}(x)dF(x) + q\int_{\overline{x}}^{\overline{\overline{x}}_1^{max}} k_{FA_1}(x)dF(x)\right) \\
& = 0 \qquad (3.A.8) \\
FOC_l^d := \quad & p\frac{\partial V}{\partial l}\left((1-q)\overline{\overline{x}}_0^{max} + q\overline{\overline{x}}_1^{max}\right) \\
& + pV\left((1-q)\frac{\partial\overline{\overline{x}}_0^{max}}{\partial l} + q\frac{\partial\overline{\overline{x}}_1^{max}}{\partial l}\right) - pr_{FA}(\beta)Z = 0 \qquad (3.A.9)
\end{aligned}$$

where

$$\begin{aligned}
Z = \quad & (1-q)\left(\int_{\overline{x}_0}^{\overline{\overline{x}}_0^{max}} \frac{\partial k_{FA_0}(x)}{\partial l}dF(x) + \overline{k}_{FA,0}\frac{\partial\overline{\overline{x}}_0^{max}}{\partial l}\right) \\
& + q\left(\int_{\overline{x}_0}^{\overline{\overline{x}}_1^{max}} \frac{\partial k_{FA_1}(x)}{\partial l}dF(x) + \overline{k}_{FA,1}\frac{\partial\overline{\overline{x}}_1^{max}}{\partial l}\right).
\end{aligned}$$

Now we can perform comparative statics on β to see how the bank's choice of p and l change when an FA is introduced (i.e. $\beta > 0$):

$$\frac{dp^d}{d\beta} = -\left(\frac{\partial FOC_l^d}{\partial p}\right)^{-1}\frac{\partial FOC_l^d}{\partial \beta} \qquad (3.A.10)$$

$$\frac{dl^d}{d\beta} = -\left(\frac{\partial FOC_l^d}{\partial l}\right)^{-1}\frac{\partial FOC_l^d}{\partial \beta}. \qquad (3.A.11)$$

The two terms in equation (3.A.10) are, respectively (taking into account that $\partial\overline{x}/\partial p = 0$, $\partial\overline{k}_{FA}/\partial p = 0$ and $\partial\overline{\overline{x}}_{max}/\partial p = 0$):

$$\begin{aligned}\frac{\partial FOC_l^d}{\partial p} &= \frac{\partial^2 V}{\partial l \partial p}\left((1-q)\overline{\overline{x}}_0^{max} + q\overline{\overline{x}}_1^{max}\right) \\ &+ \frac{\partial V}{\partial p}\left((1-q)\frac{\partial\overline{\overline{x}}_0^{max}}{\partial l} + q\frac{\partial\overline{\overline{x}}_1^{max}}{\partial l}\right) - r_{FA}(\beta)Z \end{aligned} \quad (3.A.12)$$

$$\begin{aligned}\frac{\partial FOC_l^d}{\partial \beta} &= \frac{\partial V}{\partial l}\left((1-q)\frac{\partial\overline{\overline{x}}_0^{max}}{\partial l} + q\frac{\partial\overline{\overline{x}}_1^{max}}{\partial l}\right) \\ &+ V\left((1-q)\frac{\partial^2\overline{\overline{x}}_0^{max}}{\partial l \partial \beta} + q\frac{\partial^2\overline{\overline{x}}_1^{max}}{\partial l \partial \beta}\right) - pr'_{FA}(\beta)Z - pr_{FA}(\beta)\frac{\partial Z}{\partial \beta}. \end{aligned} \quad (3.A.13)$$

At $\beta = 0$, $\overline{k}_{FA_0} = \overline{k}_{FA_0} = 0$ and $r_{FA} = 0$. Furthermore, the FOC for p reduces to $V + p\frac{\partial V}{\partial p} = 0$. These observations reduce equation (3.A.12) to $\frac{\partial^2 V}{\partial l \partial p((1-q)\overline{x}_0 + q\overline{x}_1)} > 0$, since $\frac{\partial^2 V}{\partial l \partial p} > 0$ when $\frac{\partial V}{\partial p} = 0$, and equation (3.A.13) to

$$\begin{aligned}\frac{\partial FOC_l^d}{\partial \beta} =& Vc\Bigg((1-q)\overline{x}_0\frac{p(1-q)}{(1-p)q} + q\overline{x}_1\frac{pq}{(1-p)(1-q)} \\ &- \frac{(1-q)\frac{p(1-q)}{(1-p)q} + q\frac{pq}{(1-p)(1-q)}}{(1-k)((1-q)\overline{x}_0 + q\overline{x}_1)}\Bigg), \end{aligned} \quad (3.A.14)$$

since $\frac{\partial V}{\partial l} = -V\frac{1}{(1-k)((1-q)\overline{x}_0 + q\overline{x}_1)}$ at $\beta = 0$ (following from FOC_l^d). From the latter expression it is not immediately clear whether it is positive or negative. However, for $q = 1/2$ and thus $\overline{x}_0 = \overline{x}_1 = \overline{x}$, it reduces to

$$\frac{p}{1-p}\left(\overline{x} - \frac{1}{(1-k)\overline{x}}\right) < 0. \quad (3.A.15)$$

Since $\overline{x}_0$ decreases with q and $\overline{x}_1$ increases with q equally, there must be a range of $q > 1/2$ for which expression (3.A.14) is negative (as long as expression (3.A.15) is sufficiently negative). We can now conclude that $\frac{dp}{d\beta} > 0$ at $\beta = 0$, which means that monitoring increases with β as required.

Concerning equation (3.A.11) we only need to determine $\frac{\partial FOC_l^d}{\partial l}$ (taking into account that $k_{FA}(\overline{x}) = 0$, $\partial^2 k_{FA}(x)/\partial l^2 = 0$ and $\partial^2 V/\partial l^2 = 0$):

$$\frac{\partial FOC_l^d}{\partial l} = 2\frac{\partial V}{\partial l}((1-q)\frac{\partial \overline{\overline{x}}_0^{max}}{\partial l} + q\frac{\partial \overline{\overline{x}}_1^{max}}{\partial l}) - pr_{FA}(\beta)\frac{\partial Z}{\partial l}. \tag{3.A.16}$$

At $\beta = 0$, this reduces to $2\frac{\partial V}{\partial l}\left((1-q)\frac{\partial \overline{x}_0}{\partial l} + q\frac{\partial \overline{x}_1}{\partial l}\right) < 0$. Combining this and equation (3.A.13) evaluated at $\beta = 0$, we obtain that $\frac{dl}{d\beta} < 0$. This means that as β increases, liquid reserves decrease and thus investment increases, as required.

Proof of Lemma 3.1:

Following our assumptions on $R_{FA}(\beta)$, we conclude there is a unique value of β for which $E[g|x > \overline{x}] = 1$ if $E[g|x > \overline{x}]$ is monotonically increasing in β. We call this value β^1. To see why this is the case, we can rewrite our expressions for $E[g_i|x > \overline{x}]$:

$$E[g_0|x > \overline{x}] = Pr[x > \overline{x}_0]\frac{\frac{r_{FA}(\beta)(1-q)p^e-(1-p^e)q}{p^e(1-q)}k_{FA_0}(E[x|x > \overline{x}_0]) + \beta c}{V(p^e, l)},$$
$$E[g_1|x > \overline{x}] = Pr[x > \overline{x}_1]\frac{\frac{r_{FA}(\beta)(qp^e-(1-p^e)(1-q)}{p^e q)}k_{FA_1}(E[x|x > \overline{x}_1]) + \beta c}{V(p^e, l)}.$$

We can see that these are negative at $\beta = 0$. Their derivatives w.r.t. β are

$$Pr[x > \overline{x}_0]\frac{r'_{FA}(\beta)k_{FA_0}E[x|x > \overline{x}_0] + c}{V(p^e, l)}, \tag{3.A.17}$$
$$Pr[x > \overline{x}_1]\frac{r'_{FA}(\beta)k_{FA_1}E[x|x > \overline{x}_1] + c}{V(p^e, l)}. \tag{3.A.18}$$

These are positive for all $\beta > 0$, and for $E[g_i|x > \overline{x}_i] \geqslant 1$ we need a β such that

$$E[g_0|x > \overline{x}_1] \geqslant 1 \text{ and } E[g_1|x > \overline{x}_1] \geqslant 1. \tag{3.A.19}$$

Given that $\frac{\partial E[g_i|x > \overline{x}_i]}{\partial \beta} > 0$ for all β and $i = 0, 1$, and $\frac{\partial V}{\partial \beta} = 0$, condition (3.A.19) will hold for large enough β.

Proof of Proposition 3.5:

Equation (3.32) is optimized according to the following FOCs:

$$\mathrm{FOC}^e_p := \left(\frac{\partial V}{\partial p} + pV\right)(1-(1-q)\int_{\overline{x}_0}^{1} g_0 \, dF(x) - q\int_{\overline{x}_1}^{1} g_1 \, dF(x)) = 0 \tag{3.A.20}$$

$$\begin{aligned}\mathrm{FOC}^e_l := \; & p\frac{\partial V}{\partial l} - p(1-q)\left(\int_{\overline{x}_0}^{1} g_0 \frac{\partial V}{\partial l} dF(x) - V(\frac{\partial g_0}{\partial l} - \frac{\partial \overline{x}_0}{\partial l} g_0(\overline{x}_0))\right) \\ & - pq\left(\int_{\overline{x}_1}^{1} g_1 \frac{\partial V}{\partial l} dF(x) - V(\frac{\partial g_1}{\partial l} - \frac{\partial \overline{x}_1}{\partial l} g_1(\overline{x}_1))\right) = 0\end{aligned} \tag{3.A.21}$$

where $\overline{x}_i = \overline{x}_i(p^e, l^e)$. As it is not straightforward to write an explicit solution for both p^e and l^e from these conditions, we again perform comparative statics on β. Using Lemma 1, we can analyze what happens if we go from $E[g_i|x > \overline{x}] = 1$ to $E[g_i|x > \overline{x}] < 1$, i.e. if β decreases below β^1. We apply the Implicit Function Theorem to equations (3.A.20) and (3.A.21):

$$\frac{dp^e}{d\beta} = -\left(\frac{\partial \mathrm{FOC}^e_l}{\partial p}\right)^{-1} \frac{\partial \mathrm{FOC}^e_l}{\partial \beta} \tag{3.A.22}$$

$$\frac{dl^e}{d\beta} = -\left(\frac{\partial \mathrm{FOC}^e_l}{\partial l}\right)^{-1} \frac{\partial \mathrm{FOC}^e_l}{\partial \beta}. \tag{3.A.23}$$

The two terms in equation (3.A.22) are, respectively:

$$\begin{aligned}\frac{\partial \mathrm{FOC}^e_l}{\partial p} = & \frac{\partial V}{\partial l} + p\frac{\partial^2 V}{\partial l \partial p} \\ & - (1-q)(\int_{\overline{x}_0} (\frac{\partial V}{\partial l} + p\frac{\partial^2 V}{\partial l \partial p}) g_0 \, dF(x) - (V + p\frac{\partial V}{\partial p})\frac{\partial g_0}{\partial l} dF(x)) \\ & - q(\int_{\overline{x}_1} (\frac{\partial V}{\partial l} + p\frac{\partial^2 V}{\partial l \partial p}) g_1 \, dF(x) - (V + p\frac{\partial V}{\partial p})\frac{\partial g_1}{\partial l} dF(x))\end{aligned} \tag{3.A.24}$$

$$\frac{\partial FOC_l^e}{\partial \beta} = -p\left((1-q)\left(\int_{\overline{x}_0}^{1}\frac{\partial V}{\partial l}\frac{\partial g_0}{\partial \beta}+V\frac{\partial^2 g_0}{\partial l\partial \beta}dF(x)-V\frac{\partial g(\overline{x}_0)}{\partial \beta}\frac{\partial \overline{x}_0}{\partial l}\right)\right.$$
$$\left.+q\left(\int_{\overline{x}_1}^{1}\frac{\partial V}{\partial l}\frac{\partial g_1}{\partial \beta}+V\frac{\partial^2 g_1}{\partial l\partial \beta}dF(x)-V\frac{\partial g(\overline{x}_1)}{\partial \beta}\frac{\partial \overline{x}_1}{\partial l}\right)\right) \tag{3.A.25}$$

Evaluating these equations at β^1 and noting that $\frac{\partial g_i(\overline{x}_i)}{\partial \beta} = c/V$, $\frac{\partial V}{\partial l}\frac{\partial g_i}{\partial \beta}+V\frac{\partial^2 g_i}{\partial l \partial \beta} = \frac{r'_{FA}(\beta)}{x}$ for $i \in \{0,1\}$ and $p\frac{\partial V}{\partial p}+V=0$ and $\frac{\partial V}{\partial l}+p\frac{\partial^2 V}{\partial l\partial p}>0$ in equilibrium, they reduce to:

$$\frac{\partial FOC_l^e}{\partial p} = \left(\frac{\partial V}{\partial l}+p\frac{\partial^2 V}{\partial l\partial p}\right)\left(\int_0^{\overline{x}_0}(1-q)dF(x)+\int_0^{\overline{x}_1}q\,dF(x)\right)>0 \tag{3.A.26}$$

$$\frac{\partial FOC_l^e}{\partial \beta} = -p\left((1-q)\left(\int_{\overline{x}_0}^{1}-\frac{r'_{FA}(\beta^1)}{x}dF(x)-\frac{c}{1-k}\right)\right.$$
$$\left.+q\left(\int_{\overline{x}_1}^{1}-\frac{r'_{FA}(\beta^1)}{x}dF(x)-\frac{c}{1-k}\right)\right)>0. \tag{3.A.27}$$

We can thus conclude that $\frac{dp^e}{d\beta}<0$, which means p increases as β decreases from β^1.

To determine the sign of equation (3.A.23) we only need to determine the sign of the first term on its righthand side:

$$\frac{\partial FOC_l^e}{\partial l} = p(1-q)\left(\frac{\overline{x}_0}{\partial l}\left(2g_0(\overline{x}_0)\frac{\partial V}{\partial l}+\left(\frac{\partial g_0}{\partial l}\Big|_{x=\overline{x}_0}+\frac{\partial g(\overline{x}_0)}{\partial l}\right)V\right)\right.$$
$$\left.+\int_{\overline{x}_0}^{1}2\frac{\partial g_0}{\partial l}\frac{\partial V}{\partial l}-\frac{\partial^2 g_0}{\partial l^2}VdF(x)\right)$$
$$+pq\left(\frac{\overline{x}_0}{\partial l}\left(2g_1(\overline{x}_1)\frac{\partial V}{\partial l}+\left(\frac{\partial g_1}{\partial l}\Big|_{x=\overline{x}_1}+\frac{\partial g(\overline{x}_1)}{\partial l}\right)V\right)\right.$$
$$\left.-\int_{\overline{x}_1}^{1}2\frac{\partial g_1}{\partial l}\frac{\partial V}{\partial l}+\frac{\partial^2 g_1}{\partial l^2}VdF(x)\right). \tag{3.A.28}$$

It turns out that, evaluated at β^1, $\frac{\partial^2 g_i}{\partial l^2} V = -2\frac{\partial g_i}{\partial l}\frac{\partial V}{\partial l}$ for $i \in \{0, 1\}$, and after some more simplifications equation (3.A.28) reduces to

$$\begin{aligned}\frac{\partial FOC_l^e}{\partial l} =& -\frac{p}{1-k}(1-q)\left(\frac{1}{V\overline{x}_0}\frac{r_F A(\beta)(1-q)p-(1-p)q}{(1-q)p}\right) \\ & -\frac{p}{1-k}q\left(\frac{1}{V\overline{x}_1}\frac{r_F A(\beta)pq-(1-p)(1-q)}{pq}\right) < 0,\end{aligned} \tag{3.A.29}$$

so $\frac{dl^e}{d\beta} < 0$ and thus liquid reserves decrease as β decreases to below β^1, meaning that investment increases as required.

4

A DYNAMIC ANALYSIS OF BANK BAILOUTS AND CONSTRUCTIVE AMBIGUITY

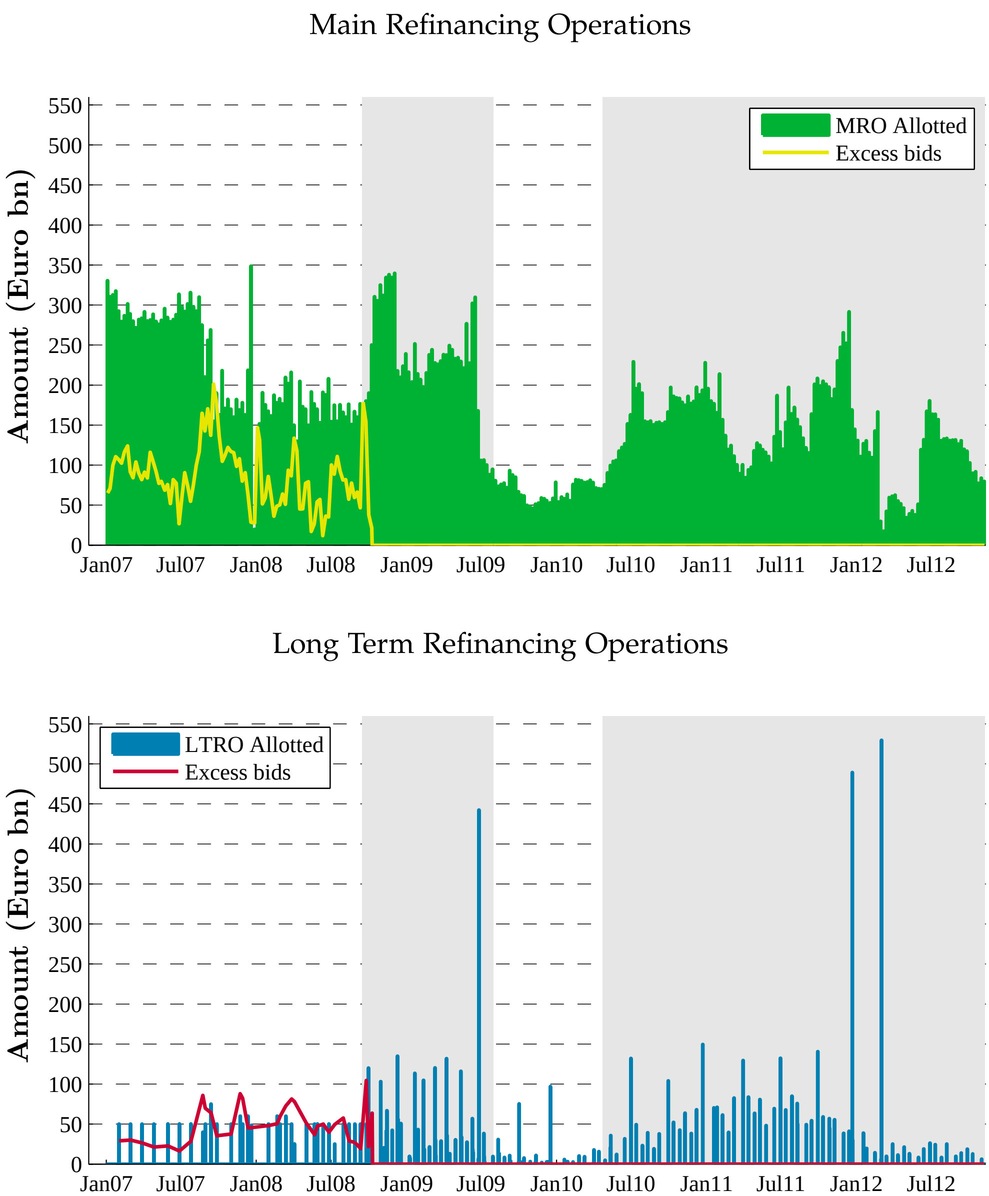
This chapter is based on Eijffinger and Nijskens (2012).

4.1 INTRODUCTION

After the recent financial crisis, calls for new regulation have dominated the academic debate. While this first centered on how to manage crises better, the debate has now moved towards reforming prudential regulation and setting up a sustainable financial system with safeguards. The current Basel capital requirements have not put much emphasis on banks' excessive maturity mismatches. Banks have relied increasingly on short-term funding to invest in long-term assets (Brunnermeier and Pedersen, 2009). Apart from prudential regulation, the Lender of Last Resort (LLR) or bailout function of central banks has come under discussion. While central banks worldwide have intervened heavily in interbank markets to alleviate the crisis, they have also been criticised. This criticism mainly focuses on the forbearing behaviour of regulators, and the moral hazard their policies have generated: banks took excessive risks knowing that they would be provided with liquidity. They also held too little capital and were relying too much on short term funding to finance long term investments.

The large scale bailouts during the 2008-2009 crisis, not only by central banks but also by national governments (Levy and Schich, 2010), have proven that the banks were right. And although governments have slowly decreased their exposure to the banking system since 2010, the European Central Bank (ECB) has not ceased providing liquidity. To restore confidence in interbank markets as a response to the current Eurozone crisis, the ECB has even increased the intensity and maturity of its assistance. We can see this in Figure 4.1: while its main refinancing operations (with 1

Figure 4.1: ECB refinancing operations



Note: This figure illustrates the short- and long term open market operations of the ECB since 2007. This is not a continuous process; especially the LTRO are performed relatively infrequently. To clarify: the bars depict how many funds have been provided to the system, while the red line indicates the amount of bids that exceeded the amount allotted. This means there has been full allotment from 2009 onwards. Furthermore, the grey areas indicate the global financial crisis and the current Euro crisis, respectively. Source: http://www.ecb.int/mopo/implement/omo/html/top_history.en.html or 2 week maturity) have remained relatively stable since 2010, the ECB has increased its long term assistance (at least 3 month maturity). The recent outliers in the graph at the bottom of the figure represent the exceptionally large liquidity injections of December 2011 and February 2012, which also have a very long maturity of 3 years. Furthermore, the figure also shows that the ECB has honored all requests for liquidity since 2009 as there is so-called "full allotment" (no excess bids for liquidity). These two developments show a clear commitment by the central bank that it will provide banks with liquidity for a significant period of time; this resembles the Federal Reserve's promise to keep interest rates low until at least the end of 2014. Taken more broadly, this could even be interpreted as solvency instead of liquidity assistance.

However, these commitments have still not persuaded banks to provide funds to the real sector or to reduce their holdings of (very) risky assets; on the other hand, this may also be due to difficulty in selling these assets. To alleviate the moral hazard problem facing central banks it has been argued that a central bank should adhere to an ambiguous emergency lending strategy (Freixas, 1999; Kocherlakota and Shim, 2007; Shim, 2011). This means that it will ex ante not state whether it will assist the bank or not; instead, the bank can expect to be assisted only with some probability. This practice of so-called "constructive ambiguity" has been more common in the monetary policy context, where it also often linked to incomplete transparency (see Geraats (2002); Cukierman (2009), and Eijffinger and Hoeberichts (2002); Demertzis and Hughes Hallett (2007) for evidence). However, as opposed to monetary policy, in the practice of assisting banks one often has to act very fast in deciding whether a bank will be assisted or not.

Furthermore, banking regulation is not a one-shot game: a bank raises funds and invests them continuously. More importantly, decisions that the bank makes now (i.e. regarding its capital structure) will have an impact on its future profitability and ability to withstand liquidity shocks. The regulator also takes this into account, as better capitalized banks and banks that have more liquid reserves are more likely to be assisted when they knock on the regulator's door for emergency assistance.

Recent investigations into the reform of the LLR function have focused on different aspects of the LLR, but not often in a dynamic context focusing on constructive ambiguity[1]. Kahn and Santos (2005), for instance, focus on the allocation of LLR responsibility between different agencies. More recently, Eijffinger and Nijskens (2011)[2] have analyzed the roles of the central bank and the fiscal authorities in providing liquidity and solvency assistance, respectively. However, both these analyses assume a static context without considering ambiguity. Regarding penalty rates and the LLR, Repullo (2005) and Castiglionesi and Wagner (2011) have both found that penalties increase risk taking by banks and regulatory forbearance. They focus, however, only on bank risk taking. The analyses most similar to ours are Goodhart and Huang (2005) and Shim (2011), who allow for multiple time periods and ambiguity, but either do not incorporate bank incentives at all or do not allow for liquidity choice.

Our approach differs from the abovementioned papers in that we allow for multiple time periods, but also explicitly take the banker's incentives into account. Furthermore, we focus explicitly on liquidity problems, leaving out solvency considerations. We set up a model of an economy consisting of one bank and one regulator with a Lender of Last Resort mandate from society. They operate in an environment without (functioning) interbank markets, i.e. a crisis episode. The bank can choose the structure of its balance sheet, while the regulator has to decide whether to assist the bank or not when it runs into trouble. In our analysis we want to focus on the incentives for the bank to hold too little capital and liquidity, and investigate the institutional details of capital and liquidity requirements in a dynamic context. Moreover, we assess the effects that failure costs and possible emergency lending penalties have on the choices of the bank and the regulator.

We find that it is optimal for the regulator to follow a mixed strategy: announcing that the bank will never be assisted is too costly for society, and therefore not credible, while always providing liquidity to the bank with certainty causes moral hazard by the banker. In response to this mixed strategy, the bank will choose capital and liquid-

1 A good overview of two decades of research on LLR and closure policy can be found in Freixas and Parigi (2008).
2 The model presented in this paper borrows some features of our earlier model.

ity above the minimum requirements. However, when these requirements or the costs of capital and liquidity are too high, the bank will not keep more than the minimum capital or liquidity. For current LLR policy our results imply that the institution responsible for liquidity assistance should be ambiguous about whether it will assist a bank or not.

This result is depending on the existence of a commitment technology for the regulator: it should have enough credibility to adhere to this strategy of constructive ambiguity. A legally binding mandate from society, together with accountability and credibility of the regulator, can accomplish this. We will elaborate upon this in the next section, where we will also relate this commitment technology to the monetary policy literature.

Furthermore, our analysis also shows that charging a lump sum penalty for LLR assistance improves the bank's incentives to hold more capital and reserves. Finally, increasing the bankers' time horizon can have positive effects on the assistance probability and capital, although the amount of liquid reserves decreases. In the next section we present our institutional environment in more detail.

4.2 INSTITUTIONAL SETUP

We consider an economy that consists of a single bank and a regulator, which we call the CBFS (Central Bank/Financial Supervisor), who both operate during two time periods. These periods consist of several stages. In the first stage, the decisions are made by both players. The bank chooses its liability structure by setting capital and liquidity and its asset structure by choosing between investing in risky assets and liquid reserves. The CBFS decides on its Lender of Last Resort policy by to choosing a certain liquidity assistance policy in the first stage of every period.

In the second stage of each period a liquidity shock occurs. This means that a fraction of deposits will be withdrawn randomly (as in i.e. Repullo (2005) and Eijffinger and Nijskens (2011)). The bank will have to use its own liquid reserves to cope with this shock; we assume that there is no access to an interbank market. This resembles a crisis situation, similar to that of the 2008 financial crisis and even the current situation in the interbank market.

Therefore, when the bank cannot cope with the liquidity shock itself, it can go to the CBFS for liquidity. This resembles the situation many European banks are in at the moment, with the ECB acting not only as a lender, but even as a full-fledged market maker of last resort. In our analysis, when the bank turns to the CBFS for liquidity, the latter has to decide whether to provide liquidity assistance to the bank or not. In case of liquidity assistance, the bank will receive the amount of liquidity necessary to repay the withdrawing depositors, and it has to pay a lump sum penalty to society at the end of each period. This penalty explicitly does not accrue to the CBFS to not distort its incentives and those of the bank (Castiglionesi and Wagner, 2011).

This structure requires there exists a commitment technology for the CBFS, enabling it to adhere to constructive ambiguity. Our CBFS is a credible authority with a sound reputation that has received a Lender of Last Resort mandate from society. It is accountable to society but independent in its decision-making. Because of its independence it is plausible that the CBFS has discretion over its policy decisions; in the monetary policy literature this type of credibility has been a standard assumption since the 1980s (Barro and Gordon, 1983; Lohmann, 1992). Alternatively, we can think of the bank not having complete information about the CBFS's objective ex ante. This uncertainty can be reflected in the composition of the CBFS's governing board: the bank may not know the exact proportion of hawks and doves in the board, and can thus not know how strict the CBFS will be. It will have to form a belief about the CBFS's objective function, and the resulting bailout probability, that will prove to be correct in equilibrium. We will come back to this interpretation later.

In the third stage the return on the illiquid asset realizes. If this is positive, the bank will reap the rewards, pay back the regulator and continue into the next period. The bank keeps its capital, and profits are consumed or partly invested into new capital that can be put to productive use. If, however, the risky asset pays off zero the bank fails, the CBFS loses its liquidity injection and a new bank owner will be put in place.

The game between bank and CBFS starts again from scratch in the next period.

The choices of the bank have different effects on the equilibrium payoffs in our model. To begin with, when the banker finances the bank with his own capital (instead of deposits) this has several advantages. First of all, the size of the possible shock decreases as the ratio of deposits to total liabilities is lower. This also increases the probability of continuing into the next period. Furthermore, a higher capital ratio increases the probability that the CBFS assists the bank if necessary. Finally, profit in period 2 increases, since initial capital has positive value in period 2, but is already fully paid for in period 1. The disadvantage of funding the bank with capital is that it reduces profit in period 1, since the costs of capital are increasing more than proportionally with investment in capital. Liquid reserves have the benefit that they increase the capability of coping with liquidity shocks. This means that they also increase the probability of continuing into the next period. The disadvantage of liquidity, however, is its opportunity cost: it reduces the amount of assets available for risky investment, and thus the profits from this investment. Table 4.1 summarizes this institutional setup as an overview of the players' choices in both time periods.

Table 4.1: Overview of players and their choices

Player	Choices
Bank	Capital, deposits, liquidity, risky assets
CBFS	Liquidity assistance policy

How does our approach differ from the existing literature? To begin with, there are not very many analyses of LLR assistance and ambiguity, and even less that take place in a dynamic context. A natural first example is the analysis by Freixas (1999), who analyzes the optimal behaviour of the LLR in response to the choice of uninsured debt by banks. A crucial assumption is that the LLR finds rescuing banks costly. As never assisting a bank is not credible (this would be even more costly, especially for large banks), the LLR engages in "constructive ambiguity": it follows a mixed strategy in rescuing the bank. A drawback of this analysis is that it only considers the liability side of the bank; no specific attention is paid to liquidity management.

Cordella and Levy-Yeyati (2003) also touch upon constructive ambiguity: they argue against it. Their analysis demonstrates that having a clear, unambiguous emergency lending policy creates a charter value effect that outweighs the moral hazard costs. Yet again, these authors do not take into account liquidity management and the effect this can have on the bank's demand for liquidity assistance.

The abovementioned analyses take a static perspective. To our knowledge there are only a few studies that employ a dynamic framework. A notable example is Goodhart and Huang (2005), who analyze the decision of whether a central bank should engage in open market operations to manage liquidity or whether it should provide direct LLR assistance. They conclude that a Too-Big-to-Fail policy can be rationalized, but only when moral hazard is the sole concern. In case contagion is also a concern, this is the main reason for LLR assistance, leading to a Too-Many-to-Fail policy. Although the authors provide a very thorough analysis of the central bank's incentives, they do not take into account the incentives of the bank manager; an issue that our analysis focuses on.

Another, more recent, example of LLR in a dynamic context is Shim (2011). He sets up a model containing hidden risk choice, private information on returns, limited commitment by the bank owner and costly liquidation. In his analysis, he finds that a combination of capital requirements and risk-based deposit insurance can implement an optimal allocation. This is coupled with a stochastic liquidation policy, i.e. constructive ambiguity. In contrast to our analysis, his focus lies more on capital regulation rather than on both liquidity and capital requirements.

Finally, we have to note that our model does not contain any uncertainty about the regulator's objectives (as in Cukierman and Meltzer (1986)). In this respect, our model differs from those by Caballero and Krishnamurthy (2008), Vinogradov (2012), Bosma (2011) or Cukierman and Izhakian (2011). We abstract from this uncertainty; in our analysis, the bank and the regulator know each other's objectives, but each makes choices that are unobservable to the other ex ante. Nevertheless, this remains an important issue, and in section 4.4 we come back to this.

4.3 THE MODEL

Our model takes the same basic assumptions about bank choices as in Eijffinger and Nijskens (2011), except for the choice of monitoring p. Instead, the bank chooses its capital ratio. To start with, let us consider an economy consisting of one bank and one regulator. There are two time periods, indexed by $t = 1, 2$, to allow us to focus specifically on the effect of period 1 decisions on period 2. Each time period consists of several stages that will be described below. Figure 4.2 on page 88 clarifies the description that will follow.

At $t = 1$ one unit of funds is required to set up a bank[3]. The bank owner faces only limited liability. He chooses how many of his own funds to invest in capital, denoted by i_t. The rest is raised by attracting deposits d_t, such that $i_t + d_t = 1$. The net deposit rate is normalized to zero (we assume deposits are insured, so they are risk-free), and the bank cannot influence this rate: there is a perfectly elastic supply of deposits at an exogenous rate of zero[4]. We also assume that the depositor base is sticky, so the amount of deposits chosen in period 1 is the same as that in period 2, so $d_1 = d_2 = d$.

Capital investment entails a cost $\phi(i_t)$, which is a convex function. Capital (especially equity) is often assumed to be costly because of adverse selection, agency or transaction costs (Holmstrom and Tirole, 1997; Hellmann et al., 2000; Estrella, 2004). Other, bank-specific reasons may be that capital leads to liquidity reduction (Diamond and Rajan, 2000) or that the banker has a certain opportunity cost of funds (Repullo, 2005). The reason why these costs are convex in our model is that convexity facilitates an interior solution for capital investment (Mehran and Thakor, 2011), as we will

3 This effectively normalizes period 1 bank size to one. This should not be a problem as we do not focus on Too-Big-to-Fail issues. Alternatively, we can fix the size of liabilities by fixing the deposit rate or by assuming a decreasing deposit supply function

4 This allows us to focus on the liquidity and capital choices of the bank, without having to consider competition issues. This assumption can be rationalized by considering, for instance, a large foreign market for deposits or by assuming that the outside option of depositors is equal to the offered deposit rate.

describe below. Investment in capital augments the capital stock k_t, according to the following law of motion:

$$k_t = k_{t-1} + i_t \tag{4.1}$$

with $k_0 = 0$. Since the total endowment is equal to 1, we can thus use this law of motion to determine that $d \equiv 1 - k_1$.

When he has set up the bank, the banker can choose to allocate funds towards two different assets. The long term asset a_t has a positive gross return $R > 1$[5] with probability p; with probability $1-p$ the return on a_t will be zero and the bank fails. The other asset l_t is a short term storage technology, which can be liquidated at any time during the period but generates a zero return for sure (risk-free). This can be summarized in the following balance sheet:

Assets	Liabilities
l_t	d_t
a_t	k_t

We can then write end-of-period bank value as follows:

$$V_t = Ra_t + l_t - d_t, \tag{4.2}$$

which, using $d \equiv 1 - k_1$, $a_t = d + k_t - l_t$ and the cost function $\phi(i_t)$, translates to expected end of period profit

$$\Pi_t = p[(R-1)(d + k_t - l_t) + i_t - \phi(i_t)]. \tag{4.3}$$

During each time period, a liquidity shock $\tilde{x}_t \sim U(0,1)$ occurs after the bank has made its decisions. It leads to a withdrawal of deposits amounting to $x_t d$, where x_t is the realization of $\tilde{x}_t$.

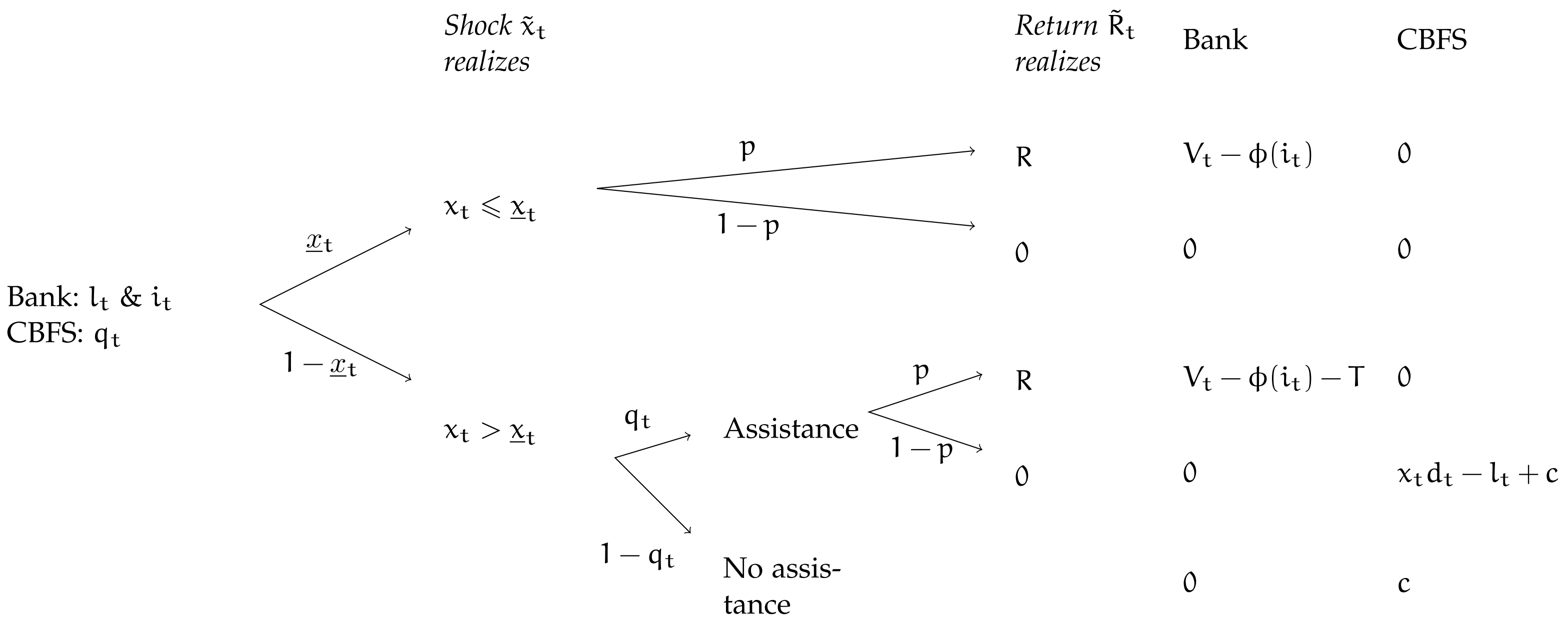
5 For an interior solution, regularity requires that $R < 2$ as well. This seems reasonable, as $R > 2$ corresponds to a net return of more than 100% which is not very realistic.

If the bank has enough liquid reserves relative to deposits, it can cope with the shock. This means that the withdrawn amount has to be smaller than the amount of liquid reserves, or $x_t d < l_t$. From this expression we can deduce a threshold $\underline{x}_t = l_t/d$, below which the bank can meet the liquidity demand. The probability that this happens is $\Pr[x_t < \underline{x}_t] = \underline{x}_t$, since x_t is uniformly distributed.

However, when liquid reserves are not adequate to meet the liquidity demand after a shock ($x_t > \underline{x}_t$ with $\Pr[x_t > \underline{x}_t] = (1 - \underline{x}_t)$), the bank will fail if it is not assisted by the CBFS. If it is assisted by the CBFS, the bank will have to pay a lump sum penalty T, that accrues to society via the deposit insurance fund. This penalty is smaller than the excess return on risky investment: $T < R - 1$. This gives the bank owner sufficient incentive to set up a bank. Additionally, the penalty is smaller than the costs of bankruptcy ($T < c$). If it is larger, the CBFS will always rescue the bank, which is not in the interest of the bank owner itself as this rescue will be expensive for the bank.

In the final step the return on the risky asset realizes. If this is equal to R, the remaining depositors are repaid, bank profits realize and the bank continues. If it is equal to zero, the bank fails, depositors are reimbursed via the deposit guarantee fund and the current bank owner will get 0. A new bank owner, again with endowment 1, will recapitalize the bank in the next period.

Figure 4.2: Sequence of events at period t



Note: this sequence is followed in time period 1 and repeated in period 2. The last two columns describe the bank's profit and the CBFS's loss, respectively. Furthermore, the CBFS incurs no loss when the bank fails in case of a small liquidity shock: as the CBFS has not been required to make a decision, it will not be held responsible for any bank failures.

Under the above assumptions, we can write expected per period profit as follows:

$$E[\Pi_t] = (\underline{x}_t + (1 - \underline{x}_t)q_t)\Pi_t - p(1 - \underline{x}_t)q_t T, \tag{4.4}$$

where q_t is the probability of assistance determined by the CBFS (this process will be described below). From the perspective of the current bank owner period 2 profit only matters when the bank succeeds in period 1 and continues to period 2. We can write a continuation probability that depends on the bank's own choices and that of the CBFS:

$$\Pr[\text{Continue}]_t \equiv p(\underline{x}_t + (1 - \underline{x}_t)q_t).$$

Using this and denoting the discount factor by β we can connect the two periods:

$$E[\Pi] = E[\Pi_1] + p(\underline{x}_1 + (1 - \underline{x}_1)q_1)\beta E[\Pi_2], \tag{4.5}$$

which is the objective the bank wants to maximize by choosing l_1, i_1, l_2 and i_2. This equation tells us that the choices of liquidity and capital in period 1 do not only affect profit at $t = 1$, but also the probability that the bank will continue into period 2. This probability increases when x_1 increases due to liquidity or capital, but it is also dependent on q_1, which is determined by the CBFS.

Before we explain the regulator's objectives, one last remark about the choice of i_2 is in order. The bank owner can raise deposits only at $t = 1$. At $t = 2$, he can only use the profits from the previous period to increase capital and thus the size of the bank. We assume that the depositor base is fixed, and that no sale of capital is allowed ($i_2 > 0$). As will be explained below, the no sale constraint will never be met. Furthermore, capital investment in period 2 does not affect anything but the amount of available assets for investment. The capital investment i_2 is thus determined by a very simple cost benefit analysis (for more details see the appendix):

$$R = \phi'(i_2). \tag{4.6}$$

Additionally, capital and liquid reserves are subject to minimum requirements, which are denoted by $\underline{k}$ and $\underline{l}$, respectively. These will play a role in determining the equilibrium values of capital and liquidity, as we will see in the next section. In the end, the banker faces a trade-off between profits (by increasing leverage) on the one hand, and the risk of liquidity problems and facing the regulator on the other.

The CBFS is the only source of liquidity for the bank beyond its own liquid reserves. After observing a shock, the CBFS will decide whether it intervenes and provides the bank with liquidity, or whether it lets the bank fail. In the latter case, the remainder of the bank will be seized by the deposit insurance fund (a passive authority), which pays out the remaining depositors, and a new bank owner with endowment 1 will be put in place. Additionally, the CBFS will incur the costs of bank failure c, which can be thought of as disruptions in the payment system, misallocation of funds or the destruction of lending relationships; in general, c represents problems with financial intermediation that are related to decisions made by the CBFS.

As we have described in section 4.2, the CBFS can credibly follow a certain liquidity assistance strategy *ex ante*. This does not have to be a pure strategy in all periods; the CBFS can also follow a policy that specifies a certain probability q_t with which the bank will be rescued[6]. In determining this probability, the CBFS will weigh the costs of intervening against the costs of letting the bank fail. The costs of letting the bank fail are the (social) costs of bank failure c. The costs of intervention will only realize when the bank fails at the end of the period, i.e. when the investment does not succeed with probability $1-p$. These costs consist of the amount of liquidity provided, and the social bank failure costs that arise since the bank has failed. The amount of liquidity

6 This q_t can also be interpreted as a proxy for the proportion of hawks and doves on the CBFS's governing council; this proportion determines the likelihood of the CBFS assisting a bank in distress.

provided is equal to $x_t d - l_t$. Denoting not assisting the bank by f (for failure) and rescuing the bank by r, we can write the respective losses as follows:

$$
\begin{aligned}
L_t^f &= c \\
E[L_t^r] &= (1-p)(\underbrace{x_t d - l_t}_{\textit{liq. support}} + c).
\end{aligned}
$$

As we can see the bank's choices also determine the size of these costs: the more capital and liquidity the bank chooses, the lower the costs of assisting the bank are. The expected value of x_t, conditional on it being larger than $\underline{x}_t$, is

$$\int_{\underline{x}_t}^{1} x_t df(x_t) = (1-\underline{x}_t)E[x_t|x_t > \underline{x}_t]. \tag{4.7}$$

Using equation (4.7) and the probability of assistance q_t we arrive at the following per period CBFS expected loss function:

$$E[L_t] = (1-\underline{x}_t)[(1-q_t)c + q_t(1-p)(E[x_t|x_t > \underline{x}_t]d - l_t + c)]. \tag{4.8}$$

Aggregating across periods, we can write the CBFS loss function as follows (γ is the CBFS discount factor):

$$E[L] = E[L_1] + \gamma E[L_2]. \tag{4.9}$$

By choosing q_t, the CBFS will want to minimize its loss function. For regularity, we further assume that the CBFS will never intervene when the bank's capital and liquidity are at the bare minimum; if we would not assume this, the bank would clearly engage in moral hazard immediately. This will be formalized in the next section.

4.4 A DYNAMIC EQUILIBRIUM

To establish the equilibrium of our dynamic game, we first solve the CBFS's problem, as this is the most straightforward one. The CBFS will want to minimize $E[L]$ w.r.t q_t. Closer scrutiny of this objective shows that this problem is not truly dynamic in q_t; the CBFS's problem consists of two separate problems. Therefore, the conditions for an interior solution for both q_1 and q_2 follow from the CBFS's First Order Conditions (FOC) in both periods:

$$\frac{\partial E[L]}{\partial q_1} = (1-\underline{x}_1)(-c+(1-p)(\frac{1}{2}(\underline{x}_1+1)d_1 - l_1 + c)) = 0 \tag{4.10}$$

$$\frac{\partial E[L]}{\partial q_2} = \gamma(1-\underline{x}_2)(-c+(1-p)(\frac{1}{2}(\underline{x}_2+1)d_2 - l_2 + c)) = 0. \tag{4.11}$$

Taking into account that $(1-\underline{x}_t)$ is a probability and γ a discount factor we know that these are always nonnegative, so the above conditions translate to

$$1-\frac{2pc}{1-p} = l_1 + k_1 \quad \text{and} \quad 1-\frac{2pc}{1-p} = l_2 + k_1, \tag{4.12}$$

which again translates to

$$l_1 = l_2 = 1-\frac{2pc}{1-p} - k_1. \tag{4.13}$$

For this condition to hold as an interior equilibrium, in which the CBFS plays a mixed strategy and the bank chooses liquidity and capital above the minimum, we have to assume that $1-\frac{2pc}{1-p} > \underline{l}+\underline{k}$. As is mentioned above, this means that the CBFS will never provide liquidity when both liquidity and capital are at the minimum.

The bank will maximize its expected profit $E[\Pi]$ w.r.t. l_1, i_1, l_2 and i_2. The FOC for this problem we have put in the appendix because of space considerations. As we now have all conditions to establish the reaction functions of bank and CBFS, we can solve them to obtain an equilibrium. As follows from the proposition below, this equilibrium does not involve strategies in which the bank will be either always or never assisted.

Proposition 4.1: *in equilibrium, the CBFS will not play a pure "always assist" strategy in any period. The CBFS is also not able to credibly commit to a "never assist" strategy.*

Proof: see appendix. ■

We can intuitively explain the proof for a mixed strategy as follows; it goes by contradiction and its intuition resembles that in Freixas (1999). To start with, an unconditional "always rescue" policy ($q_t = 1$ for $t = 1, 2$) will generate clear moral hazard problems: the bank will choose its capital and liquidity buffers to be as low as possible, which is too costly for the CBFS. It is thus never optimal to provide assistance with probability 1. A "never rescue" policy ($q_t = 0$ for $t = 1, 2$) is also not sustainable, albeit for more subtle reasons: in this case the bank will self-insure against liquidity shocks. It will choose less leverage at $t = 1$ and more liquidity in both periods, even above the capital and reserve requirements. Technically, this leads to capital and liquidity being too high for the CBFS to be able to sustain a strategy of never rescuing the bank. More intuitively, this policy is not credible for the CBFS to commit to, as always letting the bank fail will be excessively costly.

For "never assist" and "always assist" equilibria to be ruled out, only a few additional parameter assumptions have to be made. One is that the penalty that the bank faces in case of rescue is smaller than the profit it can make on its risky investment ($T < R - 1$). If this is not the case, the bank owner will not want to start up the bank as his expected profit will always be negative. Furthermore, the probability of success and return should not be too large, lest the CBFS will choose to always lend to the bank as a high probability of success reduces the cost of liquidity assistance: $\frac{2p}{1-p}c < 1$. This means that the condition on T and R can be specified even stricter (as we show in the appendix): $T < \frac{2p}{1-p}c(R-1)$, which is a necessary condition for a "pure assist" strategy to be ruled out in equilibrium. The last assumption is that the penalty should also be smaller than the social cost of bankruptcy ($T < c$) to prevent distortion of the CBFS's incentives.

The only sustainable equilibrium is thus a mixed one: the probability of rescue in any period lies between 0 and 1. A mixed strategy Nash equilibrium always exists in a finite game such as ours, which means that there is an equilibrium with $\{q_1, q_2\} \in (0, 1)$, $\{l_1, l_2\} \in (\underline{l}, 1)$, $i_1 = k_1 \in (\underline{k}, 1)$ and $i_2 \in (0, 1)$. In this completely mixed equilibrium, the bank chooses capital and liquidity above the minimum required, while the CBFS plays a mixed strategy. However, as proposition 4.2 below states, the equilibrium can also be only partly mixed; the bank will choose either minimum capital or minimum liquidity in equilibrium.

Proposition 4.2: *there exists a unique equilibrium consisting of a mixed strategy for the CBFS and, depending on minimum capital and liquidity requirements, the convexity of the cost of capital and the return on risky investment, different strategies for the bank. In this mixed strategy equilibrium, the level of liquidity is the same in both periods, while there is a trade-off between capital and liquidity in period 1.*

More specifically:

1. *If capital costs are high enough ($\phi(\cdot)$ is sufficiently convex), the bank will choose capital in period 1 to be at the minimum required: $i_1 = k_1 = \underline{k}$. Liquidity in both periods will be higher than when $k_1 > \underline{k}$, to fulfill condition (4.13).*
2. *If R is high enough and $\phi(\cdot)$ not too convex, the bank will keep liquidity at the minimum: $l_1 = l_2 = \underline{l}$. Capital will be higher than when $l_1 = l_2 > \underline{l}$, to fulfill condition (4.13).*

Proof: see appendix. ■

This proposition explains that, when capital costs are too high (i.e. quite convex), the bank will choose to satisfy the CBFS's indifference constraint by choosing more liquidity and minimum capital. On the other hand, when the return on the risky asset is too high, the bank will keep less liquid reserves and choose a higher capital ratio at $t = 1$ [7]. The following corollary elaborates upon this.

7 Note that there may also be parameterizations of $\phi(\cdot)$ and R for which $i_1 = k_1 = \underline{k}$ and $l_1 = l_2 = \underline{l}$. As we have assumed that $\underline{l} + \underline{k} < 1 - \frac{2pc}{1-p}$, this will result in an equilibrium with $q_1 = q_2 = 0$, which we have ruled out.

Corollary 4.1: *minimum capital and liquidity requirements increase the likelihood of partial corner solutions; an equilibrium with either l_t or i_t at the minimum requirement is more likely when $\underline{k}$ and $\underline{l}$ increase.*

Proof: following from Proposition 4.2, when the cost of capital or R is high, the bank will choose minimum capital or minimum liquidity. If these minimum levels are higher, they will be reached more easily. In other words, $\phi(\cdot)$ or R have to increase less for corner solutions to hold. ■

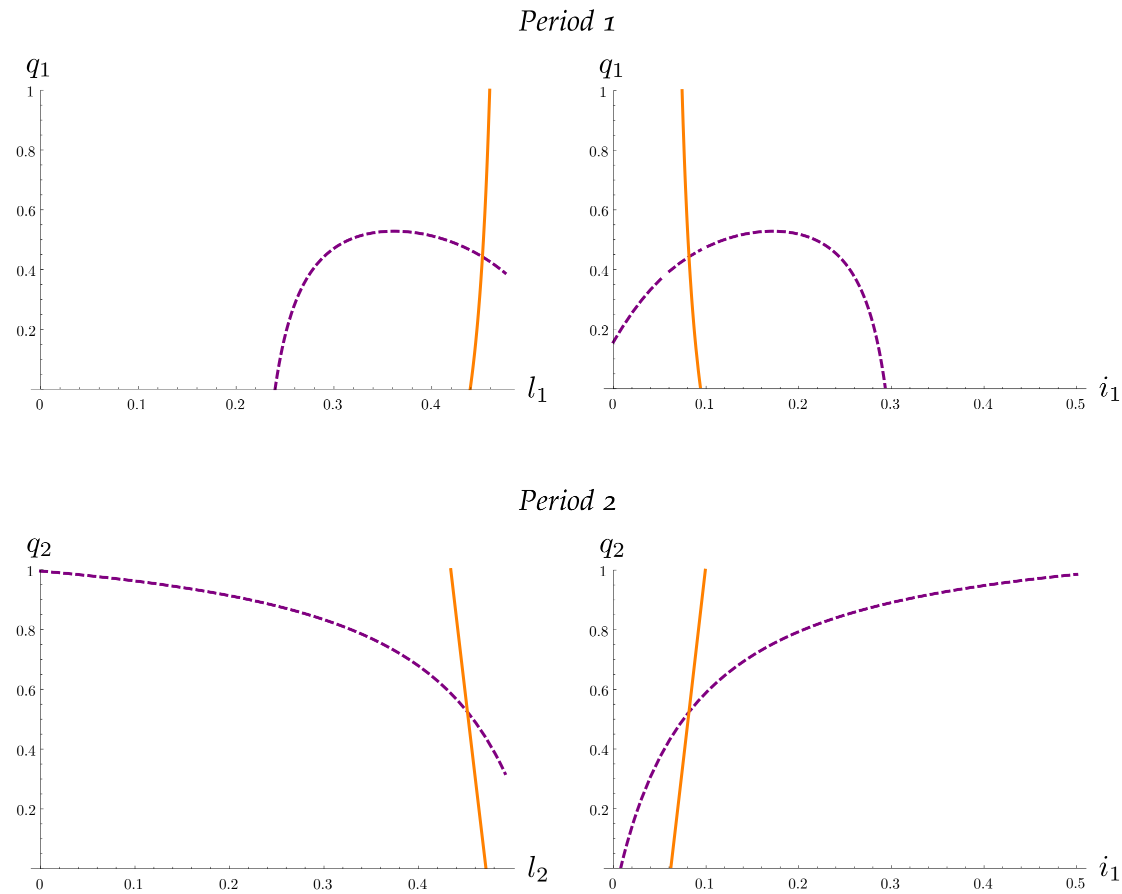
The above corollary states that when minimum capital or liquidity requirements increase, the bank will be more likely to choose a capital or liquidity ratio at the minimum when the opportunity costs for both variables increase.

To clarify the reasoning behind Propositions 4.1 and 4.2 and Corollary 4.1, Figure 4.3 displays the reaction functions of the bank and the CBFS[8]. We immediately see that the CBFS will never set q_1 to 1, so an "always assist" strategy is not feasible. The equilibrium is clearly an interior one. Note that in equilibrium liquidity is indeed equal in both periods, and that both right hand figures feature i_1 on the horizontal axis: investment in period 2 does not play a role in determining the assistance probability in our model. Finally, we can see the reasoning behind Proposition 4.2 and Corollary 4.1: if the opportunity cost of either liquidity or capital increases, the bank's reaction functions shift to the left. If this shift is strong enough, or the minimum requirement on liquidity or capital is high enough, the intersection point of the reaction functions may lie at the minimum requirement.

As a final note on the solution, the existence of this equilibrium is of course under the implicit assumption that the regulator can commit to a mixed strategy over multiple time periods. If this assumption could not hold, the equilibrium would not be time-consistent. In section 4.2, however, we have already noted that this assumption derives from the monetary policy literature: the central bank is a credible, transparent and independent authority that can commit ex ante to a specific strategy.

8 The parameter values used for this figure are $\underline{l} = 5\%$, $\underline{k} = 5\%$, $R = 1.2$, $p = 0.7$, $\beta = 0.95$, $T = 9\%$ and $c = 10\%$. The cost function is $\phi(i_t) = i_t + 4i_t^2$.

Figure 4.3: Reaction functions of the bank and the CBFS



Note: the solid line represents the bank's reaction function, while the dashed line represents the CBFS's.

Several mechanisms can serve as the basis for this commitment technology. Of course, in a repeated game the most straightforward commitment device is reputation as in Barro and Gordon (1983) and Backus and Driffill (1985). We can also think of the objective or technology of the CBFS as being ambiguous in itself. Cukierman and Meltzer (1986) already suggested this: they provide a theory of a monetary policymaker whose preferences are stochastically determined, but who has more information about their realization than the public. This ambiguity can also mean, for instance, that the bank does not know the exact magnitude of the bank failure costs c that are imposed on the CBFS if the bank fails (Bosma, 2011); the CBFS does know this. In equilibrium, the bank then has to rely on signals about these failure costs to determine its belief. As has been suggested recently, the policymaker can additionally be explicitly ambiguous about of its policy (Vinogradov, 2012; Cukierman and Izhakian, 2011). However, the effects of this type of ambiguity are not always beneficial.

Our model can be thought of as building on any of these commitment technologies; we do not specify the technology explicitly since we want to focus on the interaction between the bank and the CBFS. Exploring these different commitment mechanisms any further is, therefore, beyond the scope of this paper.

4.5 COMPARATIVE STATICS

The institutional structure of the CBFS will determine equilibrium values. Specifically, the penalty T that the bank has to pay when assisted and the social costs of bankruptcy c will play a role. Note that these are defined as fractions of the bank's size in period 1, which means they lie between zero and one.

Proposition 4.3: *the probability of liquidity assistance in both periods increases with the bank's penalty* T *and the social costs of bankruptcy* c.

Proof: see appendix. ■

An increase in the penalty T means that the bank owner has to pay more to society in the event of liquidity assistance. We can think of this as an increase in public indignation leading to a demand for bankers to pay more to society if they need assistance. The penalty then increases the probability of liquidity assistance, as it rewards prudent behaviour. This means that the bank will want to invest more in capital to avoid having to pay the penalty. Although this investment increases the probability of assistance by the CBFS, it also increases the probability that the bank can survive without any assistance and thus does not have to pay T.

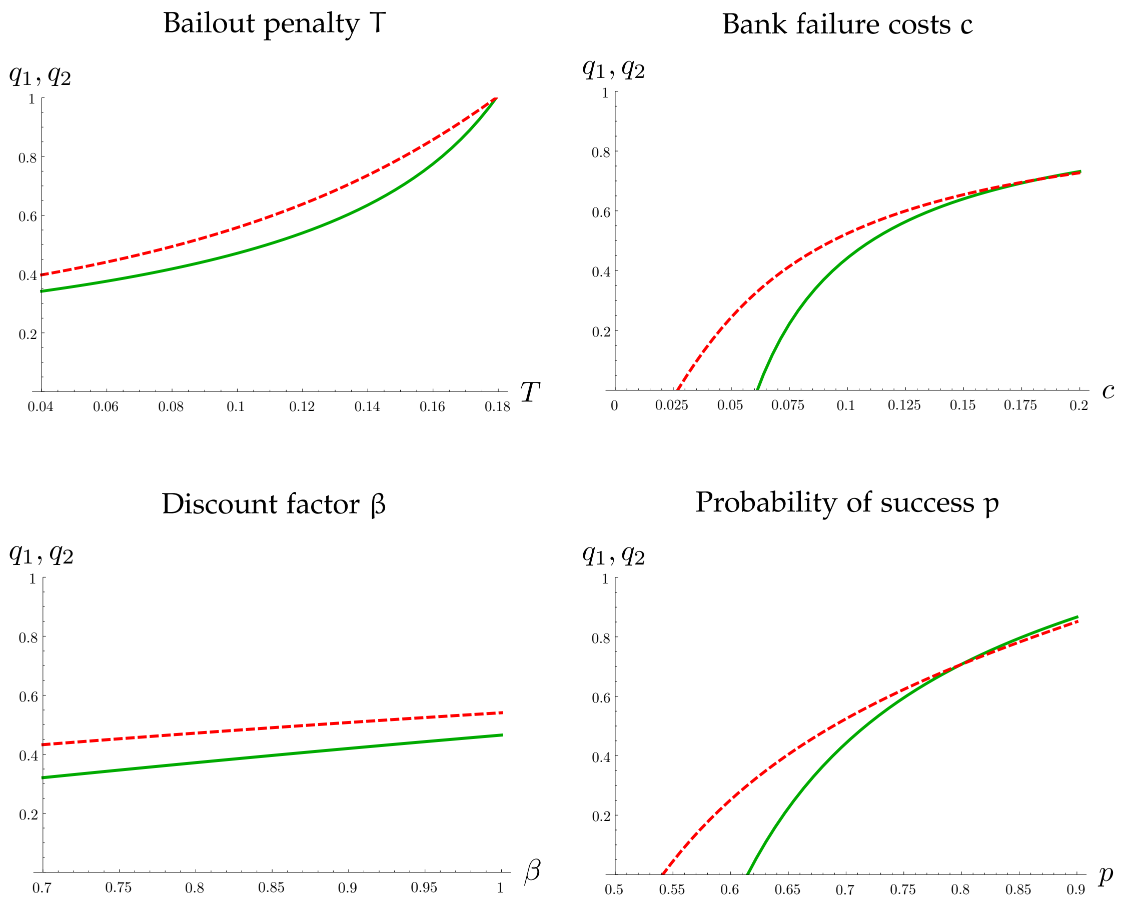
A higher cost of bank failure c means that the CBFS will incur a higher loss in case the bank fails. A higher c can reflect a change in the CBFS's mandate, increasing the responsibility the CBFS bears for the banking system. It can also reflect a stronger connection between the banking sector and the real economy (i.e. through the payment system), which means that the failure of a bank has more severe implications for the rest of the economy. Therefore, higher social costs of bankruptcy decrease the liquidity and capital levels needed to sustain a mixed strategy; a more concerned CBFS will require less investment by the banker to be able to provide liquidity assistance in equilibrium.

The effect on q_1 and q_2 of T and c is illustrated in the top row of Figure 4.4 below. This figure shows that for low values of T and c, the probability of receiving emergency liquidity in period 1 is always lower than that in period 2. The intuition behind this is that at period 1, the CBFS will want to signal that it is not very concerned about bank failure, to sustain the belief of the bank that it indeed is little concerned about failure and that the bank should keep high capital and liquidity also in the next period. In period 2 (the last period) this motive for the CBFS is no longer present, so the assistance probability can be higher. This discrepancy between periods 1 and 2 disappears as soon as c is high enough: it is no longer possible for the CBFS to sustain the bank's belief that it is not concerned about bankruptcy. A high T (above 18% of bank size under our parametrization) leads the bank to invest so much in capital that the CBFS will choose $q_t = 1$ in both periods. However, since it violates our parameter assumptions on T this will not occur in equilibrium.

Note also that there is a minimum level of c for the CBFS to be concerned; if c is too low, the CBFS will not be willing to assist the bank for any level of liquidity and capital. This minimum level is lower for q_2 than for q_1, again demonstrating that the CBFS has no concerns about the future in period 2. The CBFS will thus require less liquidity and capital investment efforts from the bank in period 2 to warrant a certain assistance probability.

Besides the institutional details of the CBFS, the probability that the bank's investment succeeds and the discount factor (the inverse of the rate of time preference) are important in determining the equilibrium outcome.

Figure 4.4: The effect of different parameters on bailout probability q_t



Note: the solid line represents q_1, while the dashed line represents q_2.

Proposition 4.4: *the probability of success* p *increases the probability of liquidity assistance, but decreases the bank's investment in capital and liquid reserves. The discount factor* β *increases the probability of assistance in both periods via an increase in period 1 capital.*

Proof: see appendix. ■

An increase in p increases the probability that the bank succeeds at the end of each period, which means that the CBFS has to worry less about the repayment of its liquidity injection. In other words, the default or solvency risk of the bank is lower. Therefore, the probability of emergency lending is positively affected by an increase in the probability of success. However, since the CBFS will be more lenient, the bank also has to invest less in capital and liquidity to satisfy the condition for a mixed strategy equilibrium.

The effect of β is more subtle. Increasing the discount factor β increases the importance of period 2 for the banker; it decreases banker myopia. He will thus want to increase both expected period 2 profit $E[\Pi_2]$ and the probability of arriving at period 2. Increasing liquid reserves decreases the amount of assets available for investment and thus the investment return in period 2. Investment in capital in period 1 increases $E[\Pi]$ and the probability of continuation after period 1 by decreasing the size of the liquidity shock and increasing the assistance probability q_1. Therefore, in period 1 the bank will want to invest more in capital and less in liquidity as the importance of period 2 increases.

The row at the bottom of Figure 4.4 shows these effects. A first observation tells us that the discount factor has limited effect; even with a discount rate of more than 40%, the probability of liquidity assistance is still far above zero. Furthermore, we can see that there exists a minimum value of the success probability p for the CBFS to be willing to assist the bank. If the probability of success is too low, the probability that the CBFS loses the liquidity it lent to the bank is too high. This is again, analogous to the minimum value of the bank failure cost c, lower for q_2 than for q_1: when setting q_1, period 2 still matters, while there is no concern about the future when setting q_2. The probability of success is thus more important in period 1 than in period 2.

4.6 CONCLUSION

Calls for new banking regulation have been numerous during the aftermath of the financial crisis. One of the main questions has been how to design a proper system of financial regulation, consisting of both prudential measures and a safety net. This system should provide protection to depositors, other debtors and the economy as a whole, while also preventing moral hazard by banks and other financial institutions.

In our model, we analyze the game between a bank and a regulator in a dynamic context, taking into account that the regulator can implement a mixed strategy in providing individual liquidity assistance. We find that unconditional assistance leads to too much moral hazard, while a policy without any assistance is not credible. Therefore, a mixed strategy, conditional on the choices of liquidity and capital by the bank, is the equilibrium solution. The bank chooses above minimum capital and liquidity, unless capital costs or the opportunity cost of liquidity are too high. In case one of either type of costs is too high, the equilibrium can still be sustained. When both are high, however, the bank will have to choose capital and liquidity to be at the minimum. In this case, liquidity assistance costs will be too high for any size of the liquidity shock, so the regulator will never assist the bank and there will be no equilibrium. We also find that the probability of emergency lending is higher for a regulator more concerned about bank failure, a bank more concerned about the future, a higher success probability and a higher the penalty for the bank. This last finding suggests that forbearance arising from penalty rates is not entirely eliminated.

As a starting point, our model takes the same basic assumptions as in Eijffinger and Nijskens (2011); the only difference is that monitoring choice is replaced by the choice of capital. We add to the existing literature by analyzing LLR policy over multiple periods, while taking into account explicitly both the regulator's and the bank's incentives. A novel result is that the only possible strategy for the regulator is a mixed one: constructive ambiguity is the only solution to our game. Furthermore, we provide the bank with two different variables to fulfill the requirements for liquidity assistance: both capital and liquidity choice can be altered to maximize the expected profit over all periods. Our final major addition to the literature is that we find an indirect forbearance effect of penalties on liquidity assistance: even though these penalties are not paid to the regulator directly, they increase the probability of assistance.

Our results can have important policy implications for reforming LLR policy. The institution responsible for liquidity assistance (preferably an independent institution like the central bank) should not state explicitly what its line of action will be. Instead, it should be ambiguous about whether it will assist an individual bank or not, and retain some discretion up until the point that the bank will ask for assistance. Our analysis also shows that it is useful to let the bank pay a (lump sum) penalty when it receives assistance, as this indeed improves the incentives to hold more capital and reserves. Finally, we find that decreasing the myopia of bankers can have positive effects on assistance probability and capital, but a negative effect on liquidity holdings.

Is this type of ambiguity policy feasible in practice? One example, albeit in a slightly different context, may be the Securities Markets Programme (SMP) of the ECB. The SMP authorizes the ECB to facilitate liquidity transformation and monetary transmission by purchasing securities in the secondary market. The SMP has been introduced on May 10, 2010 with the exact words:

"The objective of this programme is to address the malfunctioning of securities markets and restore an appropriate monetary policy transmission mechanism. The scope of the interventions will be determined by the Governing Council."[9]

The second sentence of this quote is key: the ECB Governing Council will retain discretion up to the point that assistance is needed. This means that the ECB can be ambiguous about the exact content, counterparties and conditions of this assistance ex ante. Furthermore, ex post the ECB will not publish which securities it bought, their price or the counterparties involved in its purchases; it only publishes the amount of securities bought.

We have presented a model to analyze the possibility of constructive ambiguity in lending to illiquid banks, under the assumption that the central bank has the credibility to follow this strategy ex ante. An important prerequisite for our results to hold is, therefore, the existence of a commitment technology for the regulator. As we have argued, this commitment may be provided by a mandate coupled with accountability. This should be provided to a credible authority with a good reputation, as is often the case in monetary policy. A regulator with these characteristics can internalize bank be-

9 ECB decides on measures to address severe tensions in financial markets, 10 May 2010, http://www.ecb.int/press/pr/date/2010/html/pr100510.en.html

haviour without being subject to regulatory forbearance, as it will be able to follow a strategy of constructive ambiguity. This implies that a more general setup should also encompass an analysis of this commitment technology. Therefore, a further investigation into (political) commitment mechanisms is warranted to grasp better the dynamic effects of emergency lending policies. This, however, remains for future research.

4.A APPENDIX

4.A.1 *Equilibrium Conditions*

The bank's first order conditions (FOC) for an interior solution of $\{l_1, i_1, l_2, i_2\}$ are as follows:

$$\begin{aligned}\frac{\partial E[\Pi]}{\partial l_1} &= p\left(\frac{\partial \underline{x}_1}{\partial l_1}((1-q_1)(V(l_1,i_1)-\phi(i_1))+q_1T)\right.\\&\left.\quad-(\underline{x}_1+(1-\underline{x}_1)q_1)(R-1)+\frac{\partial \underline{x}_1}{\partial l_1}(1-q_1)\beta E[\Pi_2]\right)=0 \end{aligned}\tag{4.A.1}$$

$$\begin{aligned}\frac{\partial E[\Pi]}{\partial i_1} &= p\left(\frac{\partial \underline{x}_1}{\partial i_1}((1-q_1)(V(l_1,i_1)-\phi(i_1))+q_1T)\right.\\&\quad+(\underline{x}_1+(1-\underline{x}_1)q_1)(1-\phi'(i_1))+\frac{\partial \underline{x}_1}{\partial i_1}(1-q_1)\beta E[\Pi_2]\\&\quad+(\underline{x}_1+(1-\underline{x}_1)q_1)\beta p\left[\frac{\partial \underline{x}_2}{\partial i_1}((1-q_2)(V(l_2,i_2,i_1)-\phi(i_2))+q_2T)\right.\\&\quad\left.\left.+(\underline{x}_2+(1-\underline{x}_2)q_2)\right]\right)=0\end{aligned}\tag{4.A.2}$$

$$\begin{aligned}\frac{\partial E[\Pi]}{\partial l_2} &= \beta p\left(\frac{\partial \underline{x}_2}{\partial l_2}((1-q_2)(V(l_2,i_2,i_1)-\phi(i_2))+q_2T)\right.\\&\left.\quad-(\underline{x}_2+(1-\underline{x}_2)q_2)(R-1)\right)=0\end{aligned}\tag{4.A.3}$$

$$\frac{\partial E[\Pi]}{\partial i_2} = \beta p(\underline{x}_2+(1-\underline{x}_2)q_2)(R-\phi'(i_2))=0. \tag{4.A.4}$$

From the first order conditions in equations (4.A.1) and (4.A.3) we can derive the expressions for equilibrium q_1^* and q_2^*:

$$q_1^* = \frac{V(l_1,i_1)+\beta E[\Pi_2]-\phi(i_1)-l_1(R-1)}{V(l_1,i_1)+\beta E[\Pi_2]-\phi(i_1)+(R-1)(1-i_1-l_1)-T} \tag{4.A.5}$$

$$q_2^* = \frac{V(l_2,i_2,i_1)-\phi(i_2)-l_2(R-1)}{V(l_2,i_2,i_1)-\phi(i_2)+(R-1)(1-i_1-l_2)-T} \tag{4.A.6}$$

4.A.2 *Proofs*

Proof of Proposition 4.1:

Our goal is to show that there does not exist a subgame perfect equilibrium in which the CBFS plays a pure strategy in any period. In other words, no equilibrium with $q_1 = \{0, 1\}$ and/or $q_2 = \{0, 1\}$ can be sustained. The proof makes use of backward induction and proceeds in steps.

Step 1:
Let us first consider period 2, in which the CBFS chooses q_2 and the bank chooses l_2 and i_2. Assuming that $q_2 = 1$, i.e. a full bailout at $t = 2$, we first observe that from equation (4.A.3) it follows that $i_1 = 1 - \frac{T}{R-1}$. Furthermore, as stated in the text we make an auxiliary (technical) assumption that $\frac{T}{R-1} < \frac{2pc}{1-p}$. This means that the penalty cannot be too large relative to the investment return and the cutoff point for the CBFS. Then, we have several different situations at $t = 1$:

1. $q_1 = 1$, from which follows that $l_2 > 1 - \frac{2pc}{1-p} - i_1 = \frac{T}{R-1} - \frac{2pc}{1-p}$. Equation (4.A.2) requires that $l_1 + \beta p l_2 = \frac{T}{(R-1)^2}(\phi'(1 - \frac{T}{R-1}) - (1+\beta p))$. However, a balance sheet constraint also has to be fulfilled: $l_1 + \beta p l_2 \leqslant 1 + \beta p(1 + i_2)$. From (4.A.4) we can deduce that $\phi'(i_2) = R$. We can transform this to $i_2 = \psi(R)$ by taking the function $\psi(\cdot)$ as the inverse of $\phi'(\cdot)$, or $\psi(\cdot) = \phi'^{-1}(\cdot)$ which is increasing. This leaves us with the condition

$$\frac{T}{(R-1)^2}(\phi'(1 - \frac{T}{R-1}) - (1+\beta p)) \leqslant 1 + \beta p(1 + \psi(R)). \tag{4.A.7}$$

   As $\phi(\cdot)$ is convex, $\phi'(\cdot) > \psi(\cdot)$ and $\frac{\partial(1-\frac{T}{R-1})}{\partial R} > 1$, this cannot hold for reasonably large R.

2. $q_1 = 0$, from which follows that $l_1 < 1 - \frac{2pc}{1-p} - i_1 = \frac{T}{R-1} - \frac{2pc}{1-p}$. We have assumed that $T < R - 1$ and $\frac{2pc}{1-p} < 1$. If we additionally restrict the parameter space such that $\frac{T}{R-1} - \frac{2pc}{1-p} < 0$, the above condition on l_1 cannot hold.

3. $q_1 \in (0,1)$, requiring that $l_1 = 1 - \frac{2pc}{1-p} - i_1 = \frac{T}{R-1} - \frac{2pc}{1-p}$. As $\frac{T}{R-1} - \frac{2pc}{1-p} < 0$, this is also no equilibrium.

Step 2:

Having established that a full bailout at $t = 2$ is not sustainable in equilibrium, we now consider the situation where $q_2 = 0$. This means the CBFS never assists the bank at $t = 2$. We know that this means that $l_2 < 1 - \frac{2pc}{1-p} - i_1$. The following situations can occur at $t = 1$:

1. $q_1 = 0$, which requires that $l_1 < 1 - \frac{2pc}{1-p} - i_1$. From equation (4.A.3) we can establish that

$$p(\frac{\partial \underline{x}_2}{\partial l_2}(V(l_2, i_2) - \phi(i_2)) - (\underline{x}_2)(R-1)) = 0, \text{ or} \tag{4.A.8}$$

$$V(l_2, i_2) - \phi(i_2) = l_2(R-1). \tag{4.A.9}$$

Using this and our earlier condition $i_2 = \psi(R)$, we can write i_1 as

$$i_1 = \phi(\psi(R)) - \psi(R)R + (R-1)(2l_2 - 1) \tag{4.A.10}$$

which can only be positive if

$$l_2 > \frac{R(1 + \psi(R)) - (1 + \phi(\psi(R))}{2(R-1)}. \tag{4.A.11}$$

Furthermore, $l_2 < 1 - \frac{2pc}{1-p} - i_1$ must hold. Using (4.A.10) this translates to

$$l_2 < \frac{R(1 + \psi(R)) - (\frac{2pc}{1-p} + \phi(\psi(R))}{2R-1}. \tag{4.A.12}$$

Some algebra shows that the derivative w.r.t R of the RHS of condition (4.A.11) is larger than that of condition (4.A.12) when $\psi(R) > \frac{4pc}{1-p} - 1$. This means that, for large enough R and reasonable p and c, the two conditions cannot hold simultaneously and $q_1 = 0$ cannot be an equilibrium.

2. $q_1 = 1$, leading to $l_1 > 1 - \frac{2pc}{1-p} - i_1$ and $i_1 = 1 - \frac{T}{R-1}$, which cannot be an equilibrium as we have shown above in step 1.

3. $q_1 \in (0,1)$, which requires that $l_1 = 1 - \frac{2pc}{1-p} - i_1$. Applying the same reasoning as in the $q_1 = 0$ case, this cannot be an equilibrium for reasonably large R.

Step 3:

We now move to period 1, noting that in period 2 the CBFS will always play a mixed strategy in the form of $q_2 \in (0,1)$; this establishes the relation $l_2 = 1 - \frac{2pc}{1-p} - i_1$. We now only have to show that $q_1 = 0$ and $q_1 = 1$ are not possible:

1. $q_1 = 0$, which requires that $l_1 < 1 - \frac{2pc}{1-p} - i_1$. Using condition (4.A.1) we can set up a necessary condition for l_1:

$$l_1 = \frac{\beta E[\Pi_2] + R - 1 - (\phi(i_1) - i_1)}{2(R-1)} < l_2. \tag{4.A.13}$$

We claim that this condition cannot hold if $\phi(\cdot)$ convex enough, since i_1 will be too low to sustain an l_1 below l_2. This requires that $\frac{dl_1}{di_1} < 0$, for which we apply the Implicit Function Theorem to condition (4.A.1):

$$\begin{aligned} \frac{dl_1}{di_1} &= -\frac{\frac{\partial E[\Pi]}{\partial l_1 i_1}}{\frac{\partial E[\Pi]}{\partial l_1^2}} \\ &= \frac{\beta p \frac{l_2}{(1-i_1)^2}((1-q_2)(V_2 - \phi(i_2)) + q_2 T) + 1 - \phi'(i_1)}{R-1}. \end{aligned} \tag{4.A.14}$$

This equation is negative for sufficiently convex $\phi(\cdot)$. Also, i_1 will decrease towards $\underline{k}$ when $\phi(\cdot)$ is very convex, which means that l_2 is fixed by $\underline{k}$. Thus, if i_1 decreases towards $\underline{k}$, l_1 increases and will be larger than l_2 for plausible parameter values.

2. $q_1 = 1$, leading to $l_1 > 1 - \frac{2pc}{1-p} - i_1$ and $i_1 = 1 - \frac{T}{R-1}$, which cannot be an equilibrium as we have shown above where $q_2 = 1$.

This establishes that no pure strategies are possible for the CBFS: $\{q_1, q_2\} \in (0,1)$ is the only strategy sustainable in equilibrium.

Proof of Proposition 4.2:

As stated in the text, an interior mixed strategy equilibrium always exists. As we have shown in proposition 1, $q_1, q_2 \in (0, 1)$, which means that $l_1 = 1 - \frac{2pc}{1-p} - i_1$ and $l_2 = 1 - \frac{2pc}{1-p} - i_1$, establishing that $l_1 = l_2$.
If $\phi(\cdot)$ is sufficiently convex, the FOC on i_1 in equation (4.A.2) will always be negative ($\frac{\partial E[\Pi_2]}{\partial \phi} < 0$):

$$\frac{\partial E[\Pi]}{\partial i_1 \partial \phi} = p(\frac{\partial \underline{x}_1}{\partial i_1}(-\phi'(i_1) + (1-q_1)\beta \frac{\partial E[\Pi_2]}{\partial \phi}) - (\underline{x}_1 + (1-\underline{x}_1)q_1)\phi''(i_1)$$

$$- (\underline{x}_1 + (1-\underline{x}_1)q_1)\beta p \frac{\partial \underline{x}_2}{\partial i_1}\phi'(i_2)) < 0. \tag{4.A.15}$$

This means that the bank will choose capital to be at the minimum required, establishing part 1 of proposition 2.
When $\phi(\cdot)$ is less convex and R is high enough, the FOCs on l_1 and l_2 will be negative since i_1 is relatively high and thus l_1 and l_2 relatively low (see condition (4.13) in the main text):

$$\frac{\partial E[\Pi]}{\partial l_1 \partial R} = p\left(\frac{1}{1-i_1}(1-q_1)((1-l_1) + p\beta(\underline{x}_2 + (1-\underline{x}_2)q_2)(1+i_2-l_2))\right.$$

$$\left. -(\underline{x}_1 + (1-\underline{x}_1)q_1)\right) \tag{4.A.16}$$

$$\frac{\partial E[\Pi]}{\partial l_2 \partial R} = \beta p\left(\frac{\partial \underline{x}_1}{\partial l_2}(1-q_2)(1+i_2-l_2) - (\underline{x}_2 + (1-\underline{x}_2)q_2)\right). \tag{4.A.17}$$

These expressions are negative when i_1 is relatively high, establishing that the bank chooses liquidity at $\underline{l}$ in both periods, establishing part 2 of proposition 2.

Proof of Proposition 4.3:

To gauge the effect of T on q_1 and q_2, we can employ the Implicit Function Theorem to determine the sign of the derivatives of q_1 and q_2 w.r.t T. Using equations (4.A.1) and (4.A.3) these can be written as follows:

$$\frac{dq_1}{dT} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial T}}{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_1}} \tag{4.A.18}$$

$$\frac{dq_2}{dT} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_2 \partial T}}{\frac{\partial^2 E[\Pi]}{\partial l_2 \partial q_2}} \tag{4.A.19}$$

where $\frac{\partial^2 E[\Pi]}{\partial l_2 \partial T} = \beta p q_2 \frac{\partial \underline{x}_2}{\partial l_2} > 0$. Since, in equilibrium, $l_1 = l_2$, we also know that $\frac{\partial^2 E[\Pi]}{\partial l_1 \partial T} = p \frac{\partial \underline{x}_1}{\partial l_1}(q_1 - (1-q_1)\beta \frac{\partial \Pi_2}{\partial T}) > 0$. Therefore, the numerators of $\frac{dq_1}{dT}$ and $\frac{dq_2}{dT}$ are negative. The denominators are, respectively:

$$\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_1} = p(\frac{\partial \underline{x}_1}{\partial l_1}(V(l_1, i_1) + \beta E[\Pi_2] - \phi(i_1) - T) + (1 - \underline{x}_1)(R-1)) < 0 \tag{4.A.20}$$

$$\frac{\partial^2 E[\Pi]}{\partial l_2 \partial q_2} = \beta p(\frac{\partial \underline{x}_2}{\partial l_2}(V(l_2, i_2 i_1) - \phi(i_2) - T) + (1 - \underline{x}_2)(R-1)) < 0. \tag{4.A.21}$$

As both the numerator and denominator are negative, $\frac{dq_1}{dT}$ and $\frac{dq_2}{dT}$ are positive.
The effect of c is more straightforward: as c only appears in the indifference condition of the CBFS, $l_1 = l_2 = 1 - \frac{2pc}{1-p} - i_1$, we can substitute this condition for l_1 and l_2 in the FOCs. Again applying the implicit function theorem leads us to

$$\frac{dq_1}{dc} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial c}}{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_1}} \tag{4.A.22}$$

$$\frac{dq_2}{dc} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_2 \partial c}}{\frac{\partial^2 E[\Pi]}{\partial l_2 \partial q_2}}, \tag{4.A.23}$$

of which we already know that the denominators are negative. The respective numerators are

$$\frac{\partial^2 E[\Pi]}{\partial l_1 \partial c} = p2((1-q_1)\frac{1}{1-i_1}(R-1)\frac{2p}{1-p} < 0 \tag{4.A.24}$$

$$\frac{\partial^2 E[\Pi]}{\partial l_2 \partial c} = \beta p2(1-q_2)\frac{\partial x_2}{\partial l_2}((R-1)\frac{2p}{1-p} < 0. \tag{4.A.25}$$

As again both the numerator and denominator are negative, $\frac{dq_1}{dc}$ and $\frac{dq_2}{dc}$ are positive.

Proof of Proposition 4.4:

An increase in p works through the same channel as an increase in c: we substitute $1 - \frac{2pc}{1-p} - i_1$ for $l1$ and l_2 in their respective FOCs, and then calculate the total derivative of q_t w.r.t. p:

$$\frac{dq_1}{dp} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial p}}{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_1}} \tag{4.A.26}$$

$$\frac{dq_2}{dp} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_2 \partial p}}{\frac{\partial^2 E[\Pi]}{\partial l_2 \partial q_2}}. \tag{4.A.27}$$

We already know that the denominators are negative. The respective numerators are

$$\frac{\partial^2 E[\Pi]}{\partial l_1 \partial p}|_{l_1 = 1 - \frac{2p}{1-p}c - i_1} = p2((1-q_1)\frac{1}{1-i_1}(R-1)\frac{2}{(1-p)^2}c > 0 \tag{4.A.28}$$

$$\frac{\partial^2 E[\Pi]}{\partial l_2 \partial p}|_{l_2 = 1 - \frac{2p}{1-p}c - i_1} = \beta p2(1-q_2)\frac{1}{1-i_1}(R-1)\frac{2}{(1-p)^2}c > 0. \tag{4.A.29}$$

An increase in β increases the importance of period 2 for the banker, so he will want to increase $E[\Pi_2]$. As β affects the marginal benefit of i_1 positively ($\frac{dMB(i_1)}{d\beta} > 0$, see equation (4.A.2)), without affecting its costs, the bank will want to increase i_1 to accomplish this. An increase in i_1 increases $E[\Pi_2]$, q_1 and q_2 as $\frac{dq_1}{di_1}$ is positive. The effect of β on q_1 and q_2 is reflected in the derivations below:

$$\frac{dq_1}{d\beta} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial \beta}}{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_1}} \tag{4.A.30}$$

$$\frac{dq_2}{d\beta} = -\frac{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial \beta}}{\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_2}}. \tag{4.A.31}$$

We already know that the denominators of these expressions are negative, since $\frac{\partial^2 E[\Pi]}{\partial l_1 \partial q_1} < 0$, $\frac{\partial^2 E[\Pi]}{\partial l_2 \partial q_2} < 0$ and $l_1 = l_2$ in equilibrium. The (shared) numerator is:

$$\frac{\partial^2 E[\Pi]}{\partial l_1 \partial \beta} = p\frac{\partial \underline{x}_1}{\partial l_1}(1 - q_1)E[\Pi_2] > 0, \tag{4.A.32}$$

so $\frac{dq_1}{d\beta} > 0$ and $\frac{dq_2}{d\beta} > 0$.

Through the CBFS indifference condition $l_1 = l_2 = 1 - \frac{2pc}{1-p} - i_1$ we can also see that l_1 and l_2 decline as i_1 increases. Therefore, an increase in β increases i_1, q_1 and q_2 and decreases l_1 and l_2, as required.

5

A SHEEP IN WOLF'S CLOTHING: CAN A CENTRAL BANK APPEAR TOUGHER THAN IT IS?

5.1 INTRODUCTION

In the run-up to the financial crisis the doctrine of "constructive ambiguity" has been popular with both monetary and financial stability policymakers. This means that institutions such as central banks would not be clear about their exact goals and instruments, leaving financial institutions and other agents in the dark about their intentions. Policymakers could thus follow ambiguity strategies that kept financial institutions, such as banks, vigilant and prudent.

With the advent of the crisis, however, this ambiguity has largely disappeared. Central banks and governments have intervened heavily in banks and financial markets. The case of Bear Stearns in March 2008 is a prominent example: while many believed this bank would not be assisted, it was the Federal Reserve Bank of New York who aided JP Morgan in taking over the troubled investment bank. This raised confidence, so the financial world assumed that the same would happen when Lehman Brothers faced problems six months later. The crash that followed Lehman's collapse prompted the authorities to ascertain that they were standing ready to assist other banks: ambiguity went out the window.

Jeffrey Lacker, president of the Richmond Fed, said as much when he stated that "the difficult dilemmas that policy makers faced in the fall of 2008 were in part the legacy of a financial safety net policy that ultimately proved unworkable. Often referred to as 'constructive ambiguity', this approach encouraged financial firms and their creditors to behave as if they were not protected [...] while policymakers actually were standing ready to act in a crisis."[1] The elaborate assistance programmes by the US authorities (such as TARP, but also Quantitative Easing) and the Fed's intentions to keep the interest rate low also indicate that the ambiguity doctrine has been largely abandoned, at least for systemically relevant banks.

In Europe, recent ECB actions indicate that the same view prevails here. Although the ECB does not have an explicit financial stability mandate and has not announced its objective (Vollmer, 2009), its actions and statements are a good indicator of its objectives. The liquidity operations in 2011 and 2012, dominated by two large Long Term Refinancing Operations (LTRO), already indicated in which direction the ECB is going. The statements by ECB president Draghi did the rest: "Within our mandate, the ECB is ready to do whatever it takes to preserve the euro. And believe me, it will be enough."[2] While this explicitly refers to the Eurozone crisis, it also pertains to the banking sector as these are closely linked.

On the other hand, ambiguity could still be applied to interactions with smaller or less systemically relevant banks. In Eijffinger and Nijskens (2012) analyze the effects of a CB pursuing an ambiguity strategy in this type of situation. Here, we assume that a central bank (CB) has the credibility to follow an ambiguous Lender of Last Resort (LLR) strategy. However, as follows from the observations above, this is not an obvious assumption in all situations and it deserves more exploration. In what follows, I will provide a background for the CB's credibility. As proposed by Goodfriend and Lacker (1999), CB reputation (and the ensuing credibility) can act as a commitment device for a constructive ambiguity strategy. Reputation effects play a large role in LLR policy: they can act as a disciplining device for a CB that either bails out more often (forbearance) or less often (too strict) than it should (Barro and Gordon, 1983). In other words, reputation can help distinguishing good quality from bad quality central banks (Boot and Thakor, 1993).

1 Lacker, Jeffrey M. (2010), "Reflections on Economics, Policy and the Financial Crisis", Speech at the Kentucky Economic Association, September 24, www.richmondfed.org/press_room/speeches/president_jeff_lacker/2010/lacker_speech_20100924.cfm

2 Draghi, Mario (2012), Speech at the Global Investment Conference, London, July 26, www.ecb.int/press/key/date/2012/html/sp120726.en.html

In the model this is formalized by allowing for different types of CB: tough or lenient. The bank in our model does not know this, but has to infer it from observing the actions of the CB. It then updates its beliefs about the CB's nature, according to the methodology in Backus and Driffill (1985). Operating in this framework the central bank can build a reputation for toughness by pursuing a mixed bailout strategy: constructive ambiguity. This does, however, require that the costs of a bank failure are not extremely high: it is not possible to circumvent a Too-Big-to-Fail (or systemic banking) problem with ambiguity. On the other hand, the CB's ambiguity strategy incentivizes the bank to hold more reserves, thereby alleviating bank failure problems.

This ambiguity strategy is not without risk for the CB: there is always a risk that its reputation is blown, after which it has to resort to a blanket guarantee strategy. This is of course very costly. This risk will be mitigated by an increase in bank capital buffers and, quite straightforwardly, by a high initial reputation. The latter can come in the form of political independence, as has been argued profoundly in the central banking literature. Furthermore, charging a penalty rate on bailout assistance limits the need for reputation building. Conversely, when the government stands ready to bail out any bank the bank will behave less prudently; the CB will have to exert more effort to build up its reputation.

The next section will start with a review of related literature on central banking, transparency and the Lender of Last Resort. Its second part presents a more elaborate intuitive introduction to the model.

5.2 INSTITUTIONAL DETAILS OF AMBIGUITY

Why does a central bank (CB) want to resort to constructive ambiguity? As demonstrated in Eijffinger and Nijskens (2012), it may not be able to stick to a credible no-bailout policy. However, always bailing out (a blanket guarantee) causes moral hazard and is very costly. A strategy of ambiguity is the solution to this difficult choice. Below I will argue that ambiguity requires a certain reputation, facilitated by uncertainty about the CB's objective. A short review of the literature on central bank transparency, ambiguity and its lender of last resort function will serve as an introduction to the model. After that the institutional setup of the model will be described.

5.2.1 *Literature*

In this paper I combine two strands of central banking literature: transparency and the Lender of Last Resort (LLR) function. Central bank transparency has mainly been considered in a monetary policy context in the literature. However, the degree of transparency also affects the financial stability objective of a central bank (see e.g. Van der Cruijsen et al. (2012) and Liedorp et al. (2011)).

Of course these policy areas are different: monetary policy decisions are taken quite regularly, while widespread financial crises happen infrequently. The scope for communication and transparency may therefore be limited in the financial stability context; learning about a central bank's objective is difficult when decisions are observed infrequently. However, individual banking problems that require CB involvement occur more often, giving banks more opportunities to learn about the CB's objective. In these cases following a strategy of ambiguity can be quite useful, as it can influence the bank's inference process.

The literature on central bank transparency has been comprehensively summarized by Geraats (2002), who outlines the theoretical considerations of CB transparency and touches briefly upon the empirics. A more recent overview, also incorporating newer theoretical contributions in the field of coordination and learning, can be found in Van der Cruijsen and Eijffinger (2007). An overview of the main empirical contributions to the transparency literature is provided by Blinder et al. (2008); these authors also elaborately discuss the monetary policy recommendations following from the empirical results.

Regarding central bank reputation Barro and Gordon (1983) can be seen as the seminal contribution. They propose that a government that inflates excessively to boost output can be restrained by having a credible reputation. However, the authors do not make explicit how this reputation should be achieved. Backus and Driffill (1985) have modeled the reputation building process by allowing for uncertainty about a CB's objective in a binary inflation choice setting. The public updates its belief about the CB's objective by observing whether the CB inflates or not. Barro (1986) has generalized this by allowing for reputation building in a continuous choice setting. In addition to uncertainty about the CB's objective, Cukierman and Meltzer (1986) propose that the CB has imperfect control over inflation. Control errors may hinder the public in updating its belief about the CB's type.

More recently, Faust and Svensson (2001) have extended this model structure by allowing for a more general error distribution, at the cost of more complexity. They find that transparency is, on average, socially beneficial. Sibert (2006) obtains a similar result in a simple 2 period model. A surprising result from both studies is that full transparency, i.e. revealing the exact objective function of the CB, leads to suboptimally high inflation. As the CB does not care about its reputation anymore, it will not try to build one by pursuing low inflation. A similar result (albeit in a different setting) will obtain in the formal model that is explained in section 5.3.

Empirically, Dincer and Eichengreen (2009) have updated the measurement of central bank transparency by Eijffinger and Geraats (2006). However, their focus lies on monetary policy communication, which is not the focus of my analysis. Born et al. (2011) have taken a different approach by measuring the effect of communication targeted at financial stability. By analyzing communication channels such as speeches, interviews and reports on financial stability they find that transparency is generally preferable. However, in crisis times (such as those in the model below) it pays to be less transparent as to not trigger bank runs or market panics.

The other literature related to this study is that on the Lender of Last Resort and Bailouts. A comprehensive survey of this literature is provided by Freixas and Parigi (2008). I will focus on those contributions that discuss time inconsistency and constructive ambiguity.

The time inconsistency problem is a particularly pervasive one in bank crisis management. Ex ante, a financial regulator would like to be tough to discourage a bank from behaving imprudently. When a crisis has hit, however, it is optimal for the regulator or government to save the bank and avoid the problems associated with bank failure. Acharya and Yorulmazer (2007) analyze a situation in which banks want to become more correlated to profit from a bail out. The reason is that the regulator will not want to bail out a single bank ex ante, but it will save multiple banks if they fail together: a Too-Many-to-Fail problem. Banks will thus make similar investments and thus increase the risk that they fail together, after which the regulator will rescue them. Additional to the regulator's problem, Chari and Kehoe (2009) find that also private creditors suffer from a time inconsistency problem. As they would like to avoid bankruptcy (and losing everything) they renegotiate their contracts ex post. This creates incentives for bankers to behave imprudently.

The empirical literature on bailout expectations confirms these theoretical notions. Dam and Koetter (2012), for instance, apply a structural model of political factors to the German banking system and find that bailout expectations indeed increase risk taking. Regarding the US Troubled Asset Relief Program (TARP) and its signaling effects, Black and Hazelwood (2012) find that large banks assisted through this program take significantly higher risks in new lending efforts. This result relates to the notion of Too-Big-to-Fail: in a study of bank's tail risk, Knaup and Wagner (2012) find that this tail risk is lower for big banks. They take this as an indication of an implicity bailout subsidy by the authorities. Relatedly, Carbo-Valverde et al. (2011) find that complex banks enjoy more safety net benefits as measured by the value of a put option on bank value. Finally, bailout expectations do not only increase risk taking by those banks protected by the bailout, but through increased competition can lead unprotected banks to take more risk (Gropp et al., 2011).

On the other hand, there is also evidence of a reputation building effect in the context of official bailouts (i.e. by the IMF). Dell'Ariccia et al. (2006), for instance, find that the "non-bailout" of Russia in 1998 increased sovereign debt spreads. They interpret this as a decrease in bailout expectations. It can also be seen as a confirmation of the "constructive ambiguity" doctrine[3].

3 Constructive ambiguity may have been the aim of the United States government when they did not assist Lehman Brothers; the outcome of this policy was probably not intended.

This notion of ambiguity has been emphasized in the Lender of Last Resort (LLR) literature by, among others, Freixas (1999). He argues that, to limit bank leverage, a CB acting as LLR should resort to a mixed strategy in its bailout decision. Goodhart and Huang (2005) employ a dynamic model to argue that, indeed, a CB should employ ambiguity by not letting the bank know the exact conditions under which it will be assisted; this limits moral hazard.

Several authors have recently embraced the idea of *Knightian* uncertainty: not only the CB's bailout probability, but also its distribution is unknown. In this situation agents will resort to maximin optimization: they optimize under the worst case scenario. Cukierman and Izhakian (2011) find that a sudden ex post increase in bailout uncertainty, e.g. after the failure of Lehman Brothers in 2008, leads to a higher interest rate, higher default rates and even a dry-up of credit markets. In contrast, *ex ante* low bailout uncertainty increase moral hazard through higher leverage which makes a "Lehman"-type event even more destructive. Vinogradov (2012) analyzes a similar case: uncertainty about bailout mechanisms can create a misalignment of beliefs between depositors and banks. This disrupts credit markets when aggregate risk is high.

In section 5.3 I combine the insights from the literature on central bank transparency and reputation with those from the Lender of Last Resort and bank bailout literature in a formal model. Below, I provide an intuitive approach to this model, which is used to study the effect of (less) central bank transparency on bailout expectations and bank liquidity choices.

5.2.2 *Introducing the model*

In the model, there is one bank that operates in an environment with uncertainty about the Lender of Last Resort's (LLR) objective function. The LLR is modeled as a central bank (CB) with a mandate for financial stability. However, in this mandate the CB's loss function is not very specifically defined. The bank only knows that there are different types of loss functions, that can make the CB either tough or lenient. If the

CB is tough, it will never assist a bank that runs into liquidity problems; the bank will have to obtain liquidity on its own. This type of CB will be referred to as a Hawk, a term used in the monetary policy literature to refer to an inflation-averse policymaker.

A Dove, on the other hand, is more lenient than a Hawk and will be more willing to assist the bank. In fact, a Dove will always want to rescue the bank (absent reputational concerns): a blanket guarantee. The disadvantage of this policy is that it is very costly. These costs can be overcome by making use of the uncertainty about the CB's mandate: if a bank does not know with 100% certainty that the CB is a Dove, it has to take into account the possibility that it is not rescued if necessary. This provides scope for a constructive ambiguity policy by the CB through its reputation for toughness.

It has to be noted that the "type" of CB can be interpreted more generally as the overall policy inclination of its executive board. This means that it reflects the proportion of Hawks and Doves on the board. If the board consists of predominantly Doves, the CB is referred to as a Dove; if Hawks have the majority, the stance of the CB will be Hawkish. In any case, the bank does not know the exact proportion of Hawks and Doves in the board, and thus does not know the overall policy inclination of the CB.

The bank in the model faces liquidity shocks resulting from a financial crisis, as depositors withdraw their money. In this crisis the interbank market is not functioning. Therefore, if the bank is not liquid enough it can only go to the CB for liquidity. Only by observing the CB's past actions the bank can find out whether it is dealing with a Hawk or a Dove. This will be analyzed in a repeated game setup over two time periods, so the bank can base its current period's decisions on the previous periods' results. It will have certain beliefs on the CB's nature, which will be updated on the basis of Bayes' rule as in Backus and Driffill (1985); equilibrium in the model will then be determined by these beliefs and both players' actions.

This stylized situation relates to the policy problem that the world's Lenders of Last Resort currently face. Should they act as Hawks, which keeps their reputation high but lowers bailout expectations at the risk of too many failures? Should they act as

Doves, avoiding failures but increasing the scope for moral hazard due to a decrease in reputation? Or is it even possible to return to a situation of constructive ambiguity, and under which conditions?

The current situation in Europe and the ECB's actions during this crisis seem to indicate that the ECB currently has a more Dovish stance, not only in monetary policy, but also in financial stability. The recent comments by its president, Mario Draghi, have provided even more support for this indication. In the United States the situation is similar: the Federal Reserve, for example, has indicated that interest rates will remain low until mid-2015[4].

5.3 MODEL

As stated above there are two players in the model: a bank and a central bank (CB) that operates as the Lender of Last Resort (LLR). The bank operates in an environment with uncertainty about the CB's loss function: it does not know the size of the CB's cost of bank failure θ. This parameter represents all costs that arise from bank failure and that are attributed to the CB's action (or inaction). In a broader sense it can also be seen as the net costs of failure, i.e. the difference between the costs of failure and those of a bailout.

A tough central bank (Hawk), will never rescue a bank in liquidity problems as its cost of assistance always surpasses that of bank failure. In other words, a Hawk's θ, which is denoted by θ_H, is lower than or equal to zero. A lenient central bank (Dove), on the other hand, has a positive θ_D. This means that under some circumstances it will want to assist a bank with liquidity problems and, as we will see below, does this with a positive probability q_t.

Clearly, this characterization of central bank incentives is strongly simplified and perhaps at odds with reality. In practice a central bank will always have some motivation to assist a bank with liquidity, especially when the bank is fundamentally sound.

4 Federal Reserve Board (2012), "Why are interest rates being kept at a low level?", http://www.federalreserve.gov/faqs/money_12849.htm

However, some CBs (particularly those with good reputation) may be less willing to assist than others. This can depend on the extent to which they are responsible for financial stability; this is proxied by our parameter θ. The assumptions on this parameter can be generalized such that $\theta_H > 0$ and a Hawk is also willing to assist an illiquid bank. However, as long as a θ_H is sufficiently below θ_D, our results will remain qualitatively unchanged.

The ex ante uncertainty about this θ is a process governed by Nature, and can be quantified as follows:

$$\theta = \begin{cases} \theta_H = 0 & \text{with probability } \lambda_H \\ \theta_D > 0 & \text{with probability } 1 - \lambda_H \end{cases} \tag{5.1}$$

where $\lambda_H < 1$ and no further assumptions on the size of λ_H are made. Furthermore, λ_H is perfectly observable and known to all players at the start of the game. The realization of θ takes place before the game between the bank and the CB starts, and is known only to the CB. After θ has realized, the bank and the CB play a repeated game.

5.3.1 *Bank details*

The bank has a size normalized to 1, and operates in each period t with a very simple balance sheet structure:

Assets	Liabilities
l_t	d
a_t	k

where d denotes deposits, k is capital, l_t represents liquid reserves and a_t is the amount invested in risky assets. These will be explained in more detail below.

The capital structure of the bank is taken as given, meaning that $d + k = 1$. Deposits are completely insured and thus require an interest rate equal to the risk free rate, which is normalized to 0. Capital is provided by the bank owner and can act as a buffer in case of losses. Furthermore, as we will see later it will also make the bank less vulnerable to liquidity shocks.

On the asset side we first find liquid reserves l_t. These can be seen as a storage technology gross return 1 or, equivalently, a net return equal to the risk free rate of 0. Finally, the bank can invest $a_t = 1 - l_t$ into a risky investment opportunity returning $R > 1$ with probability $p > \frac{1}{2}$ and zero otherwise. As we are mainly interested in the net returns, it is useful to define $r = R - 1$ as the net return in case of success.

Since the balance sheet size and its liability side are fixed, the bank only chooses its assets. This amounts to choosing liquid reserves l_t. As the bank faces limited liability, this will lead to the following expected end-of-period profit in autarky:

$$\Pi(l_t) = p(r(1 - l_t) + k). \tag{5.2}$$

However, the bank may be subject to a liquidity shock $\tilde{x}_t$ in an intermediate stage. This shock is distributed as follows:

$$\tilde{x}_t = \begin{cases} x & \text{with probability } \mu \\ 0 & \text{with probability } 1 - \mu \end{cases} \tag{5.3}$$

Its realization leads to a deposit withdrawal of xd. The size of x and the probability μ are known ex ante, so the expected value μx is readily calculated. This deposit withdrawal is no explicit bank run (although it may be the result of a random signal on bank solvency (Rochet and Vives, 2004), nor a liquidity shock that is required to continue an investment project as in Holmstrom and Tirole (1998). We want to abstract from the shock causing solvency problems by itself: if the bank is liquid, it will never be insolvent as a direct consequence of the liquidity shock.

Depending on the choice of l_t, two situations can emerge after the liquidity shock (note that the interbank market is not functioning):

1. $xd \leqslant l_t$: no problem
2. $xd > l_t$: assistance from CB needed

Liquidity assistance then consists of full liquidity replenishment of xd, will only happen if CB is of type D and can be denied by D for reputational reasons. To simplify our analysis the CB charges no penalty rate. I will elaborate upon this later in section 5.3.2, in which the CB's objective will be described.

Knowing that it may or may not be assisted by the CB, the bank will have to choose its liquid reserves. This amounts to a trade-off between the opportunity cost of liquidity and the expected gain from being assisted. The bank's liquidity choice is a binary one between either being liquid at $l_t = xd$ or being illiquid at $l_t = 0$. This follows from the observation that there is no gain from choosing more than xd (as the shock size is known), and it is not useful to choose less because this will not help solving liquidity problems.

Before summarizing the bank's problem in a value function, a last note about the resolution process is in order. The bank faces limited liability, which means it loses only its capital if it fails; this can be due to either illiquidity or insolvency ($R = 0$). If the bank fails at any step, it is taken over by the deposit insurance fund and resolved. In the next period a new banker will be put in place.

However, if the bank survives and $R > 0$, bank continues to $t + 1$. We have established that ex ante, the bank can choose to be liquid, which means $l_t = xd$. This happens with endogenous probability s_t. In a mixed strategy, we thus have that $s_t \in (0, 1)$. The bank will thus have the following objective:

$$\max_{l_t} \quad V_t = s_t B^L + (1 - s_t) B_t^{NL} + \underbrace{p(s_t + (1 - s_t) z_t)}_{\text{Continuation probability}} V_{t+1} \tag{5.4}$$

where

$$
\begin{aligned}
B^L &= p\Pi(xd) = p(r(1-xd)+k) \\
B_t^{NL} &= pz_t\Pi(0) = pz_t(r+k),
\end{aligned}
$$

and $z_t = (1-\mu) + \mu(1-\rho_t)q_t$ is the probability that the bank survives until the end of the period, q_t is the CB's assistance probability, and ρ_t is CB reputation. The two latter ones will be detailed in the next section. Note, furthermore, that the bank does not discount future profits.

As follows from equation (5.4), the bank's value function V_t depends on the current probability of assistance by the CB. However, it also depends on the CB's reputation explicitly: if the CB has a certain reputation for being tough ($\rho_t > 0$), the bank cannot be sure that it will receive liquidity. Reputation is ultimately determined by the actions of the CB, according to Bayes' rule. This exact process will be described in the next section.

5.3.2 *Central Bank liquidity assistance*

If a liquidity shock occurs, the Central Bank has to decide whether it assists the bank or not. Of course, this decision is a trade-off between the costs of (immediate) bank failure and the expected costs of a liquidity injection. For a H CB, this is a no-brainer: as its $\theta_H = 0$, it will never assist a bank. However, for a D CB there is a trade-off. If it lets the bank fail now (denoted by F), D faces the immediate cost θ_D. If, on the other hand, D assists (A) it may incur the cost c and lose its injection xd if $R = 0$. As the H CB does not take any action, it is left out of the analysis from now on. The D CB will be referred to as just the CB.

The per period loss functions for the CB are:

$$\text{Assistance: } L_t^A = (1-p)(xd+\theta_D),$$
$$\text{Failure: } L_t^F = \theta_D.$$

The CB's objective is thus to choose between A and F every period. Note also that, as mentioned before, the CB does not charge a penalty rate on its liquidity assistance. Several authors have demonstrated this can lead to gambling and thus more moral hazard (Castiglionesi and Wagner, 2011; Repullo, 2005). Furthermore, it may lead to forbearance by the CB (Kahn and Santos, 2005). In section 5.5 this assumption will be relaxed.

The CB also cares about its reputation. This notion has been introduced into the monetary policy literature by, among others, Barro and Gordon (1983) and has been formalized explicitly by Backus and Driffill (1985). In this model reputation is modeled as in Backus and Driffill (1985). As stated above, ρ_t is the CB's reputation for toughness. Even if it is a Dove, it can build reputation by acting as a Hawk. Reputation is updated according to Bayes' rule:

$$\rho_{t+1} = \begin{cases} \frac{\rho_t}{\rho_t+(1-q_t)(1-\rho_t)} & \text{if F} \\ 0 & \text{if A or } \rho_t = 0 \end{cases} \tag{5.5}$$

where q_t is the probability that the CB bails out. This means that reputation can only increase if the probability of bailout q_t is positive. When $q_t = 1$ and the CB's decision is A, its reputation will be blown. In other words, reputation building is risky, as a bailout action will immediately bring ρ_t to zero.

It follows that reputation in the next period (ρ_{t+1}) neatly summarizes the consequences of current CB actions. If a bailout occurs, $\rho_{t+1} = 0$, but if a bailout does not occur $\rho_{t+1} > 0$. The CB's future value function Λ_{t+1} depends on ρ_{t+1}, so there are two possibilities: $\Lambda_{t+1}(0)$ and $\Lambda_{t+1}(\rho_{t+1})$. The CB's current value function consists of current and future loss functions and depends on q_t and ρ_{t+1} (again, there is no time discounting). Its objective is to minimize this value function:

$$\min_{q_t} \quad \Lambda_t = (1-s_t)\left(q_t(L_t^A + \Lambda_{t+1}(0)) + (1-q_t)(L_t^F + \Lambda_{t+1}(\rho_{t+1}))\right). \qquad (5.6)$$

From the above equation it can be seen that if $q_t = 1$ the CB will completely blow its reputation, $\rho_{t+1} = 0$ and $\Lambda_{t+1}(0)$ will prevail at $t+1$. Furthermore, the situation in which the bank is liquid (w.p. s_t) is not included. In this case, there is no need for the CB to step in so its loss equals zero by definition.

5.3.3 *Summary and sequence*

The analysis that follows will involve a two-period version of the model described above. This enables us to study the effects of reputation on bank rescue and liquidity decisions, without needlessly complicating the analysis. One important assumption needs to be made:

Assumption 5.1: $\theta_D \geqslant \frac{(1-p)}{p}\chi d \equiv \underline{\theta}_D$.

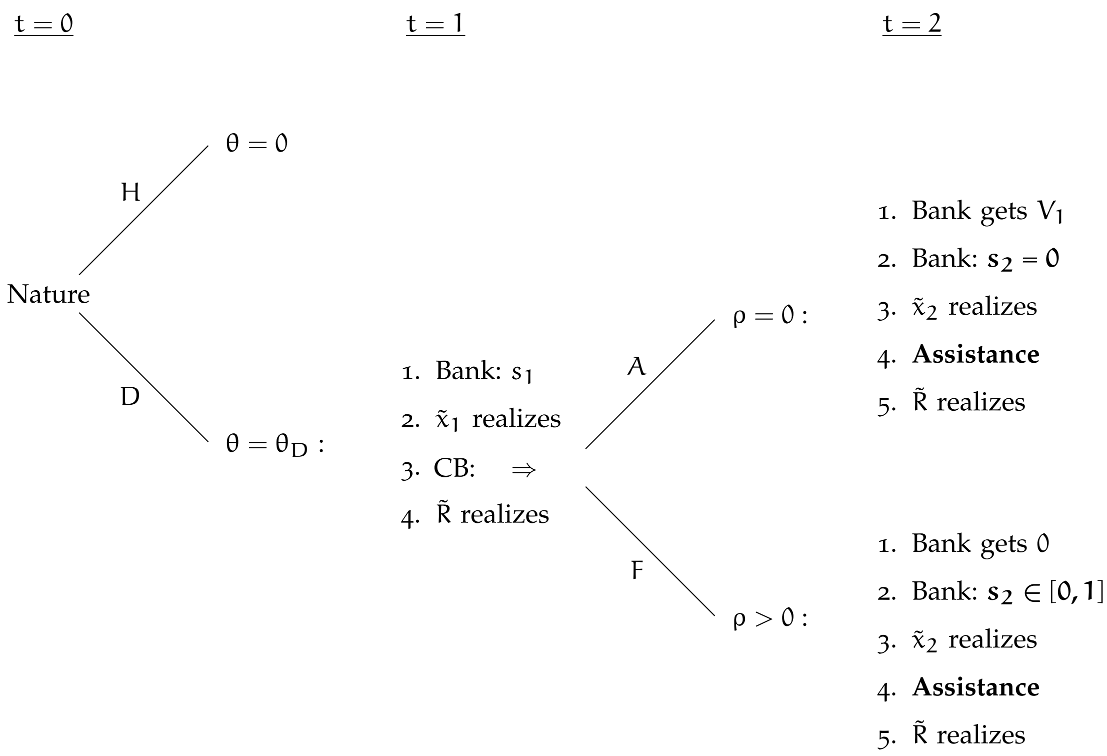
This inequality can be deduced from the observation that a Dove CB does not care about its reputation anymore in the last period; it will only weigh L_2^A against L_2^F in its bailout decision. When assumption 1 is satisfied the CB cares enough about bank failure to always rescue in the last period ($t = 2$): $q_2 = 1$ [5]. This indicates, as assumed, that a Dove CB's only reason for not bailing out the bank is its reputation in the next period.

Knowing this, the sequence of events can be summarized in Figure 5.1. It is important to note that if the CB bails out, its reputation is reduced to zero. The bank then chooses to be illiquid in the next period, as it knows it will be bailed out with

5 This is a normalization assumption, and perhaps not an innocuous one. However, it has intuitive appeal: a Dove would like to assist the bank, but does not do so solely for reputational reasons. Moreover, it greatly simplifies our analysis as solving the game in the last period is now relatively easy. Furthermore, for a sufficiently large θ_D it will be the case that $q_2 > q_1$ always.

certainty[6].

Figure 5.1: Sequence of events



5.4 REPUTATIONAL EQUILIBRIUM

In solving the model, it is convenient to start at the right side of Figure 5.1 and employ backward induction. The solution concept will be that of a Bayesian Nash equilibrium, or a sequential equilibrium.

6 Note that, as stated above, we do not incorporate discounting into the model. However, its effects would be quite straightforward: as the future matters less for both players, they will exert less effort. This means that the bank would be less liquid and the CB would choose a lower bailout probability, leading to less reputation building.

As it is already established that a D CB will always bail out in period 2 it is only necessary to consider the bank's problem in that period. At $t = 2$, the bank's objective looks as follows:

$$\max_{s_2} V_2 = s_2 B^L + (1 - s_2) B_2^{NL}$$

where

$$B^L = p\Pi(xd) = p(r(1 - xd) + k)$$
$$B_2^{NL} = pz_2\Pi(0) = pz_2(r + k),$$

and $z_2 = 1 - \mu\rho_2$ since $q_2 = 1$. In maximizing this, the bank only takes into account the consequences for the current period, taking as given the decision of the CB and the decisions from the previous period.

An important summary statistic from the previous period is the CB's reputation, which is determined by equation (5.5). Since we have two periods only, $\rho_1 = \lambda_H$ and

$$\rho_2 = \frac{\lambda_H}{\lambda_H + (1 - q_1)(1 - \lambda_H)}. \tag{5.7}$$

The bank knows this, and bases its decision for period 2, i.e. its choice of s_2, on this ρ_2. It's second period first order condition (FOC) for an $s_2 \in (0, 1)$ is:

$$rxd = \rho_2\mu(r + k), \tag{5.8}$$

which means that there is a critical ρ_2, which I will call ρ_2^*, that makes this hold. I will elaborate upon this below. What is important to observe here is that this FOC is negative when $\rho_2 = 0$: $s_2 = 0$.

At $t = 1$, the central bank's reputation is built. The CB knows that if $q_1 = 1$, ρ_2=0 and its reputation is blown: this will lead to $\Lambda_2(\rho_2) = \Lambda_2(0)$. It will thus take this into account in its objective function:

$$\min_{q_1} \quad \Lambda_1 = (1 - s_1^*)\left((1 - q_1)(L_1^A + \Lambda_2(0)) + q_1(L_1^F + \Lambda_2(\rho_2))\right)$$

where

$$\Lambda_2(\rho_2) = \begin{cases} (1-p)(xd + \theta_D) & \text{if } \rho_2 < \rho_2^* \\ (1-s_2)(1-p)(xd+\theta_D) & \text{if } \rho_2 = \rho_2^* \\ 0 & \text{if } \rho_2 > \rho_2^*. \end{cases} \tag{5.9}$$

This reflects that if reputation is high enough, the bank will choose to be liquid and thus the CB faces no costs in period 2. However, if reputation is too low (eg. 0), the CB will face full liquidity assistance costs. Note that ρ_2 is determined by q_1 according to Bayes' rule in equation (5.7).

The bank knows this information when maximizing its objective at $t = 1$:

$$\max_{s_1} \quad V_1 = s_1 B^L + (1 - s_1) B_1^{NL} + \underbrace{p(s_1 + (1 - s_1)z_1)}_{\text{Continuation probability}} V_2$$

where $z_1 = 1 - \mu + \mu(1 - \rho_1)q_1$. The choice of q_1 is taken as given by the bank, as well as its own choice at $t = 2$.

In the next section I will summarize both players' decisions and elaborate on the possible equilibria that can arise, depending on the assumptions about initial reputation $\rho_1 = \lambda_H$ and θ_D.

5.4.1 *Sequential equilibrium*

We know that under our assumptions at $t = 2$, a Dove CB will always rescue the bank: $q_2^* = 1$ (note that a $*$ indicates an equilibrium value). The CB's actions at $t = 1$ can be summarized quite neatly:

$$q_1 = \begin{cases} 1 & \text{if } \theta_D > \theta_D^* \equiv \frac{(1-p)(1+s_2^*)}{p-s_2^*(1-p)} x d \\ q_1^* \in (0,1) & \text{if } \theta_D = \theta_D^* \\ 0 & \text{if } \theta_D < \theta_D^*. \end{cases} \tag{5.10}$$

This means that the ultimate decision by the CB depends on θ_D, i.e. the weight that it attaches to bank failure, and, through equilibrium s_2^*, on its future reputation ρ_2.

The bank's actions in both periods are summarized by the following two equations:

$$s_1 = \begin{cases} 1 & \text{if } \rho_1 > \rho_1^*(q_1^*) \equiv 1 - \frac{1}{q_1^*}\left(1 - \frac{rxd}{\mu(r+k+V_2)}\right) \\ s_1^* \in (0,1) & \text{if } \rho_1 = \rho_1^*(q_1^*) \\ 0 & \text{if } \rho_1 < \rho_1^*(q_1^*) \end{cases} \tag{5.11}$$

$$s_2 = \begin{cases} 1 & \text{if } \rho_2 > \rho_2^* \equiv \frac{rxd}{\mu(r+k)} \\ s_2^* \in (0,1) & \text{if } \rho_2 = \rho_2^* \\ 0 & \text{if } \rho_2 < \rho_2^*. \end{cases} \tag{5.12}$$

These tell us that the bank's choice of liquidity at $t = 1$ depends on initial reputation $\rho_1 = \lambda_H$ and the CB's bailout probability q_1. The choice of liquidity at $t = 2$ depends on future reputation ρ_2 only, as this is a summary statistic of what has happened before $t = 2$.

Before moving to the different equilibria that can occur, another parameter assumption is needed to make sure that $p_2^* < 1$. This means that the bank can be liquid or follow a mixed strategy in equilibrium in period 2. If ρ_2^* would be larger than one, we would encounter the strange situation in which reputation can never be high enough to make the bank liquid at $t = 2$. The following assumption guarantees this will not happen.

Assumption 5.2: $rxd < \mu(r + k)$

where rxd are the opportunity costs of being liquid and $\mu(r + k)$ represents the expected gain from being liquid. In case of autarky or when the reputation of the CB $\rho_2 = 0$, the bank thus prefers being liquid to being illiquid (and risking failure in case of a shock). Thus, the only reason for a bank to not keep liquid reserves is because it may be bailed out by the Central Bank.

As I have mentioned before, different situations can arise for different values of the failure cost and reputation parameters. These are depicted in Figure 5.2, and they will be considered in turn below.

5.4.2 *A badly concealed Dove*

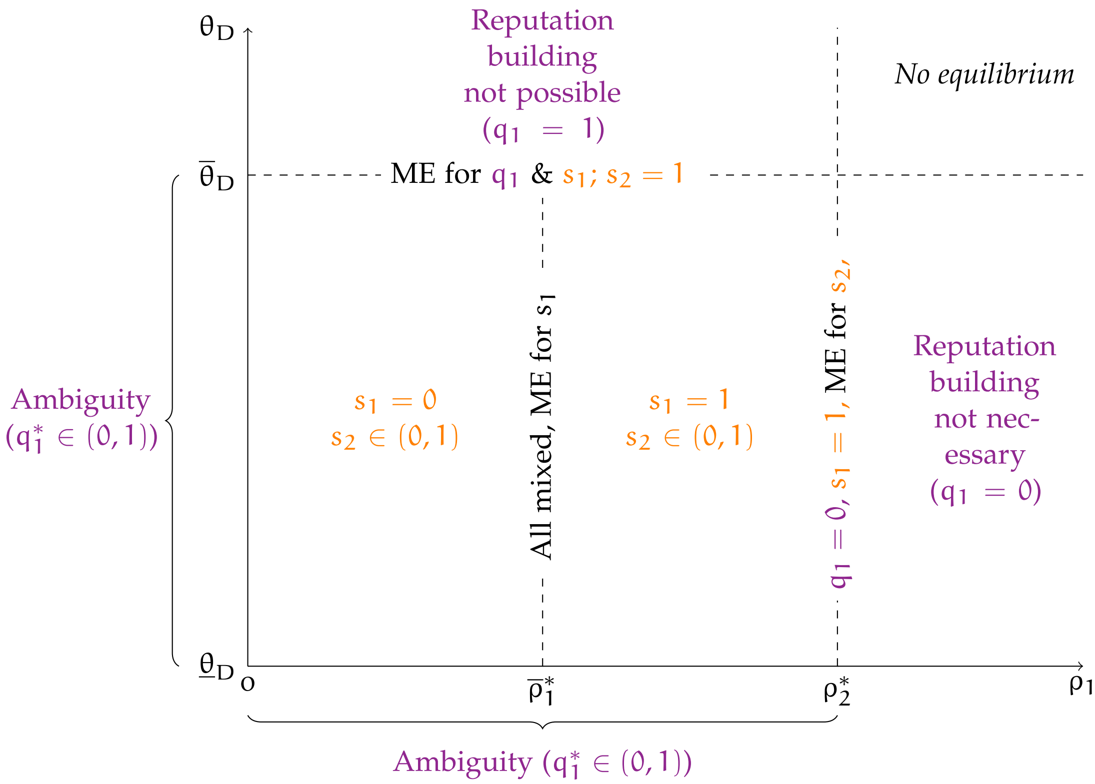
As stated in the top area of Figure 5.2, there are cases for which reputation building is not possible. These are described in proposition 5.1 and explained below.

Proposition 5.1: *if* $\lambda_H = 0$ *or* $\theta_D > \overline{\theta}_D \equiv \frac{1-p}{p-1/2}xd$ *it is not possible for the CB to build a reputation (such that* $\rho_2 > 0$*) in equilibrium.*

Proof: see appendix. ■

When the CB's reputation in period 1 is zero or the failure costs θ_D are very high, it is not possible to build a reputation. The reason behind this is that θ_D is known; if this is higher than $\overline{\theta}_D$ the CB will rescue irrespective of whether the bank is liquid or not. As this θ_D is also observable to the bank, it will choose never to be liquid ($s_2 = 0$) and the CB has no choice but bailing out the bank if necessary. Naturally, if the CB's initial reputation is already zero ($\lambda_H = 0$), it will never be able to make a bank believe it is tough since there is no uncertainty left about its nature.

Figure 5.2: Equilibria determined by failure cost and reputation



Note: q_t and s_t denote the probability of bailout and the probability of being liquid in period t; q_t indicates the CB's equilibrium strategy, while s_t indicates the bank's strategy. Each area between the (dashed) lines represents a unique equilibrium. The areas at the top, the top-right and the right represent situations in which reputation building is not possible, there is no equilibrium, or reputation building is not necessary, respectively. Finally, on the dashed lines we have multiple equilibria (ME); these are special cases.

As it is now established that reputation building is not possible for $\theta_D > \overline{\theta}_D$, I will restrict attention to those cases in which $\theta_D \in (\underline{\theta}_D, \overline{\theta}_D)$.

5.4.3 *All Central Banks are very tough*

The right-hand side of Figure 5.2 shows that there are also values of $\rho_1 = \lambda_H$ for which reputation building is not necessary.

Proposition 5.2: *if* $\lambda_H \in (\rho_2^*, 1)$ *reputation building is not necessary, so* $q_1^* = 0$ *and* $s_1^* = s_2^* = 1$.

Proof: see appendix. ■

If the CB is already seen as very tough, it is not necessary to build a reputation by choosing a positive bailout probability. The bank will therefore always be liquid in both periods without the CB having to build a reputation with a positive q_1.

Since the cases with very high failure costs and very high reputation are proven to be static, I will now only treat situations in which $\rho_1 < \rho_2^*$ and $\theta \in (\underline{\theta}_D, \overline{\theta}_D)$.

5.4.4 *Building a reputation for toughness*

In the case of intermediate failure costs, i.e. $\theta \in (\underline{\theta}_D, \overline{\theta}_D)$, it is possible for the CB to build a reputation by playing a strategy of "constructive ambiguity". This means that the central banker will, in equilibrium, choose a positive bailout probability that is below one. A high central bank reputation will make the bank more inclined to keep its own liquid reserves, as it is less certain of assistance by the CB. This will be explored below. However, it is convenient to first discuss the initial condition of the model, also called initial reputation.

The CB's initial reputation matters for its ability as well as its need to build a future reputation, which in turn determines the future liquidity position of the bank. However, it also determines whether the bank will be liquid or not in the current period: if initial reputation is low, the bank will choose not to be liquid and trust on the CB's willingness to provide liquidity. If initial reputation is high, the bank will play a safer strategy and keep its own liquid reserves to cope with the liquidity shock.

To distinguish between low and high initial reputation, I have to define a threshold. This threshold determines for which ρ_1 the bank chooses to be liquid or not in the first period, and is stated in the lemma below.

Lemma 5.1: *there exists a unique threshold for $\lambda_H (= \rho_1)$, called $\overline{\rho}_1^*$, above which the bank chooses $s_1 = 1$. Below this threshold $s_1 = 0$.*

Proof: see appendix. ■

Using this lemma and the results from the previous sections it is straightforward to state proposition 5.3. This states that reputation building is possible and worthwhile but initial reputation also matters.

Proposition 5.3: *if $\lambda_H \in (0, \overline{\rho}_1^*)$, the CB will build a reputation by choosing $q_1^* = \frac{1-\lambda_H/\rho_2^*}{1-\lambda_H} \in (0, 1)$ and the bank will not be liquid in period 1 ($s_1^* = 0$), but with positive probability $s_2^* = \frac{\frac{p}{1-p}\theta_D - xd}{\theta_D + xd} \in (0, 1)$ in period 2.*

The proof for this proposition follows from the first order conditions in equations (5.10), (5.11) and (5.12) (assuming $\theta_D \in (\underline{\theta}_D, \overline{\theta}_D)$) and Lemma 1. ■

For a low enough initial reputation (left-hand side of Figure 5.2) it is thus the case that the central bank's reputation is too low to make the bank liquid in the current period. Building a reputation is costly, as follows from equation (5.7): ρ_2 increases with q_1. The CB has to increase its (conjectured) bailout probability to obtain a higher reputation. This will be anticipated by the bank, which will be less inclined to keep its own liquid reserves when q_1 is higher. As follows from Lemma 1, if reputation is low enough the bank will choose to hold no reserves at all in period 1.

Nevertheless, as long as initial reputation is positive, it is possible to build a reputation for toughnesss by pursuing a constructive ambiguity policy. This will make the bank liquid with a positive probability in the next period.

On the other hand, if the central bank's initial reputation λ_H is high enough (right-hand side of Figure 5.2) the bank will be liquid in period 1 with certainty. This follows as a corollary from proposition 5.3.

Corollary 5.1: *if* $\lambda_H \in (\overline{\rho}_1^*, \rho_2^*)$, *the CB will build a reputation by choosing* $q_1^* = \frac{1-\lambda_H/\rho_2^*}{1-\lambda_H} \in (0,1)$, *the bank will be liquid with certainty in period 1 (*$s_1^* = 1$*) and with positive probability* $s_2^* = \frac{\frac{p}{1-p}\theta_D - xd}{\theta_D + xd} \in (0,1)$ *in period 2.*

If the CB's reputation is high enough, the bank does not expect to be bailed out with a high probability (q_1 is relatively low) so it will keep its own liquid reserves in period 1. Again, as long as the initial reputation is positive the central bank can build its future reputation in such a way that the bank is liquid with a positive probability in the next period.

5.4.5 *Border cases*

There are several border cases with multiple equilibria and one case in which there is no equilibrium at all. They are discussed informally below; proofs are available upon request.

For $\theta = \overline{\theta}_D$ and $\rho_1 < \rho_2^*$ the CB will follow a mixed strategy but there are multiple equilibria at $t = 1$ for s_1; q_1 is undetermined. For $\rho_1 = \overline{\rho}_1^*$ we have a equilibria in only mixed strategies, but s_1 is undetermined. For $\lambda_H = \rho_2^*$ reputation building is not necessary ($q_1 = 0$) and $s_1 = 1$, but s_2 is undetermined. The case without an equilibrium arises when both reputation and failure costs are high, i.e. $\lambda_H > \rho_2^*$ and $\theta_D > \overline{\theta}_D$. Here, the bank would want to be liquid always because of the CB's high initial reputation. However, since failure costs are high, the CB will always want to bail out. This means, in turn, that being liquid at $t = 1$ is not the bank's best response, and we can thus not have a stable equilibrium.

5.5 DISCUSSION

In the previous section I established that there exists an equilibrium in which the central bank plays a strategy of "constructive ambiguity" in period 1. The goal of this strategy is to build a reputation for toughness in the next period, such that the bank is liquid with a positive probability. This section will explore some of the determinants of this constructive ambiguity, and extend the model in different directions to make it more general.

5.5.1 *Environment effects*

The equilibrium in section 5.4 is parameterized on the CB's initial reputation λ_H and on the bank failure costs θ_D. However, there are several other environmental parameters that determine the CB's strategy q_1. For future reference, it is useful to restate the explicit expression for the equilibrium q_1:

$$q_1^* = \frac{1-\lambda_H/\rho_2^*}{1-\lambda_H}. \tag{5.13}$$

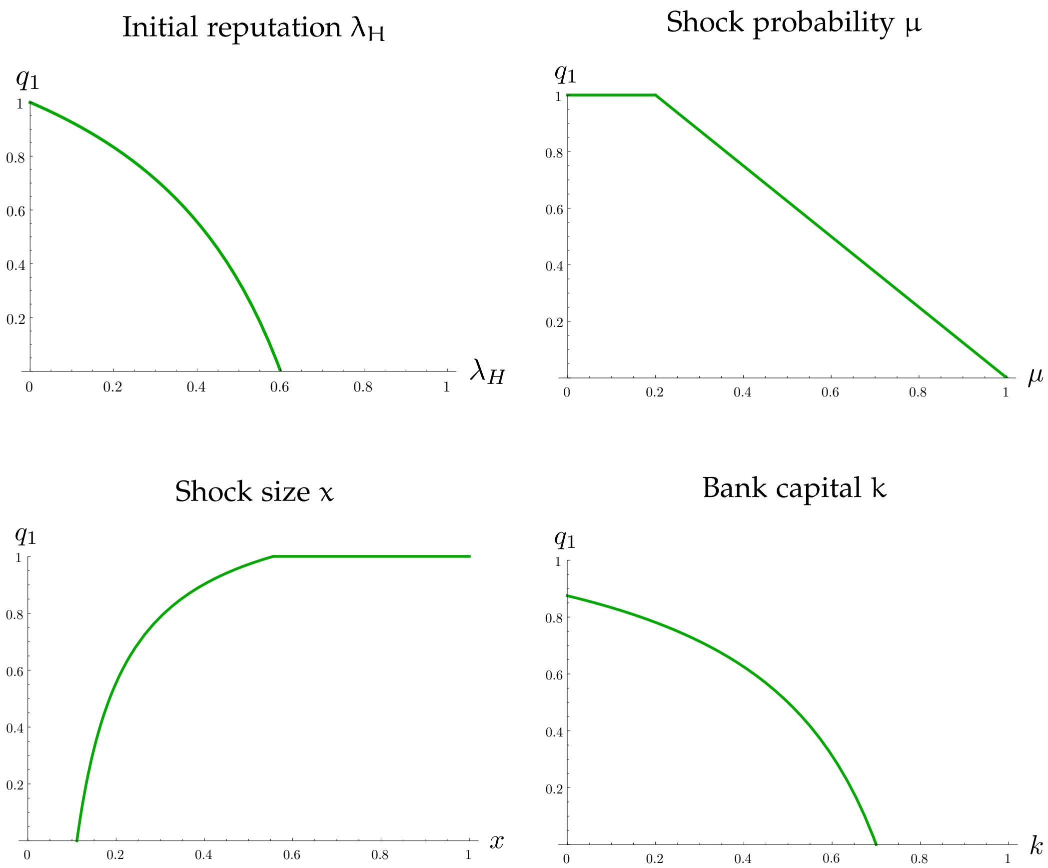
To begin with, its initial reputation not only determines *when* the central bank can play constructive ambiguity, but also to which extent it has to do so. Furthermore, the probability of the liquidity shock, its size and the bank's capital ratio play a role in determining the CB's bailout probability. These effects are summarized in the following proposition.

Proposition 5.4: *the CB's bailout probability* q_1 *decreases with its initial reputation* λ_H *and the probability of the liquidity shock* μ*, while it increases with the size of the shock. Bank capital* k *decreases* q_1.

The proof for this proposition follows straight from equation (5.13). Regarding λ_H, we see that $\frac{dq_1^*}{d\lambda_H} = \frac{rxd-\mu(r+k)}{rxd(1-\lambda_H)^2} < 0$, since the numerator is positive by Assumption 2. The comparative static effects of shock probability and size follow from $\frac{dq_1^*}{d\mu} = -\frac{\frac{(r+k)}{rxd}}{\lambda_H^{-1}-1} < 0$ and $\frac{dq_1^*}{dx} = \frac{\frac{\mu(r+k)}{rxd}}{x(\lambda_H^{-1}-1)} > 0$. Finally, the effect of bank capital is

$\frac{dq_1^*}{dk} = -\frac{(1+r)\frac{\mu(r+k)}{rxd}}{(1-k)(1-\lambda_H)} < 0.$ ■

Figure 5.3: The effect of different parameters on bailout probability q_1



Note: parameter values employed in these graphs are $r = 20\%$, $k = 8\%$, $\mu = 0.3$, $x = 0.3$ and $\lambda_H = 0.2$.

A visual portrayal of the comparative statics is presented in Figure 5.3. The intuition behind these various effects can be explained by the incentives of the CB and the bank. The reputation effect is straightforward: if reputation is already high, the CB does not have to "promise" a high bailout probability to build a reputation. In the figure we can also see that this effect can ultimately drive q_1 to zero: here, $\lambda_H > \rho_2^*$ and reputation building is not necessary anymore.

Equation (5.12) shows that ρ_2, which is determined by q_1, determines the bank's choice of s_2. q_1 is thus determined at the point of indifference of the bank; this changes with the parameters. Specifically, the probability of the liquidity shock, μ, decreases the critical reputation level ρ_2^* meaning that *less* reputation building is necessary and q_1 is lower. The size of the shock, however, has the opposite effect: it increases the opportunity costs of holding liquidity (since a higher liquidity buffer is needed) for the bank. Therefore, the bank is less willing to hold liquidity on its own and a higher reputation (i.e. higher ρ_2 and thus higher q_1) is necessary to make the bank liquid at $t = 2$. Finally, the capital effect is more direct: when the bank's capital ratio increases, the bank owner has a higher stake and will thus be more willing to hold liquidity. Hence, the CB does not have to put much effort in reputation building and q_1 can be lower.

The analysis above indicates that high initial reputation, a high shock probability and a high bank capital buffer lead to a low bailout probability, meaning that they decrease the need for reputation building. However, I have also shown that the size of the shock increases the need for reputation building because the bank's opportunity costs of liquidity increase. In the next section I will elaborate on the possibility to increase the opportunity costs of *not* holding liquidity by introducing a penalty rate.

5.5.2 *Penalty rate*

In section 5.3 I have assumed that the CB does not charge a penalty rate on its liquidity assistance; instead, the bank has to pay the risk free rate (equal to zero). Below I will relax this assumption: now, the bank has to pay a rate of $r_P < r$ on the assistance it receives from the Central Bank. This has consequences for both the bank (who has to pay the penalty) and the CB (who will receive it). These can be summarized with new per-period profit and loss functions, which will be denoted with a superscript P:

$$B_t^{NL,P} = p(z_t(r+k) - \mu(1-\rho_t)q_t r_P xd) \tag{5.14}$$

$$L_t^{A,P} = (1-p)(xd(1-r_P) + \theta_D). \tag{5.15}$$

Proceeding by backward induction again shows that Assumption 1 is still confirmed: the CB will now rescue at $t = 2$ when

$$\theta_D \geqslant \frac{(1-p)}{p} xd(1-r_P),$$

which will also hold for $\theta > \underline{\theta}_D$. The bank now has the following objective function at $t = 2$:

$$\max_{s_2} \quad V_2^P = s_2 pB^L + (1-s_2)pB_2^{NL,P}.$$

This optimization leads to a new expression for the threshold for second period reputation ρ_2. Recall that above this threshold, the bank chooses to be liquid[7]:

$$\rho_2^P = \frac{rxd - \mu(r_P xd)}{\mu(r+k-r_P xd)}. \tag{5.16}$$

The q_1 that is required to make $\rho_2 = \rho_2^P$ will also change:

$$q_1^P = \frac{1-\lambda_H/\rho_2^P}{1-\lambda_H}. \tag{5.17}$$

At $t = 1$, the bank will have the following objective:

$$\max_{s_1} \quad V_1^P = s_1 pB^L + (1-s_1)pB_1^{NL,P} + p(s_1 + (1-s_1)z_1)V_2^P$$

7 When $r_P = 0$, $\rho_2^P = \rho_2^*$ and we are back in our basic model.

taking into account that $q_1 = q_1^P$ to have an equilibrium at $t = 2$. This leads to a restatement of the critical initial reputation λ_H in equation (5.11), above which the equilibrium $s_1^P = 1$:

$$\rho_1^P(q_1^P) = 1 + \frac{1}{q_1^P}\left(\frac{rxd - \mu(r+k+V_2^P)}{\mu(r+k+V_2 - r_P xd)}\right). \tag{5.18}$$

Finally, the CB's problem in period 1 also changes (note that L^F does not change):

$$\min_{q_1} \quad \Lambda_1^P = (1-s_1^*)\left((1-q_1)(L_1^{A,P} + \Lambda_2^P(0)) + q_1(L^F + \Lambda_2^P(\rho_2))\right).$$

As in the original model, an interior q_1^* requires that the FOC from this optimization is zero. The accompanying s_2^P is:

$$s_2^P = \frac{\frac{p}{1-p}\theta_D - xd(1-r_P)}{\theta_D + xd(1-r_P)}. \tag{5.19}$$

The main question I ask is: will a penalty rate increase or decrease the need for reputation building? Another interesting one is whether the bank will be more or less liquid as a consequence. The answers to these questions are summarized below.

Proposition 5.5: *a penalty rate $r_P > 0$ decreases the need for reputation building by the CB, so $q_1^P < q_1^*$. Furthermore, the introduction of a penalty rate makes the bank liquid more often at $t = 2$ and for a larger range of initial reputation λ_H at $t = 1$.*

Proof: see appendix. ■

This result means that a penalty rate is indeed effective in making the bank more liquid and relieving the central bank of building a reputation through a high q_1 and thus a high chance of having to bailout. Two effects are at play: the bank's expected costs of a bailout increase (in the basic model they were zero) and the CB's expected loss from a bailout decreases. The former effect dominates, decreasing the CB's bailout probability and increasing the bank's willingness to be liquid.

Note, however, that I focus solely on liquidity considerations. If the bank were also able to choose the quality of its investment there would be scope for moral hazard by the banker as in Ratnovski (2009). In that case there can be a negative effect of penalty rates, as they may lead to gambling. For a more detailed investigation of this phenomenon see Repullo (2005) or Castiglionesi and Wagner (2011).

5.5.3 *Government bailout*

During (and after) the financial crisis central banks have not operated by themselves. In case of severe bank problems, such as insolvencies, national governments (and fiscal authorities in general) have provided capital assistance or guarantees to keep banks alive. The knowledge that the fiscal authorities were standing by to assist in times of crisis has altered incentives of banks, but perhaps also those of central banks.

This can be incorporated in the model in the following way. As investigated in Eijffinger and Nijskens (2011) there is a Fiscal Authority (FA) that assists the bank if a central bank does not provide it with liquidity. The FA can do this with an outright capital injection or through a more indirect debt guarantee; what is important is that the FA will demand a repayment from the bank. The repayment, let us call it g, will be a part of bank value in case of success at the end of the period: $g \leqslant 1$. The bank's profit function in case of government assistance (denoted by G) looks as follows:

$$B_t^{NL,G} = p(z_t - g(1 - z_t))(r + k). \tag{5.20}$$

This expression is a generalization of our basic model, which is the special case with $g = 1$ (full nationalization). Note that g will only have to be paid if the bank does not survive the liquidity shock, which happens with probability $1 - z_t$. The CB will not be involved in this, so its loss function is not altered[8].

8 This assumption is made for simplicity. Of course, during the financial crisis in 2008 and 2009 many central bankers were also held accountable for government bailouts (i.e. through parliamentary investigations as in the Netherlands). However, the monetary costs for these bailouts were attributed to the fiscal government.

The bank's new optimization problem at $t = 2$ is:

$$\max_{s_2} \quad V_2^G = s_2 p B^L + (1 - s_2) p B_2^{NL,G}.$$

Following from this optimization the new threshold for ρ_2 associated with government bailouts is:

$$\rho_2^G = \frac{rxd}{g\mu(r+k)}, \tag{5.21}$$

from which follows that $\rho_2^G = \rho_2^*$ for $g = 1$. The q_1 that is required to make $\rho_2 = \rho_2^G$ will also change:

$$q_1^G = \frac{1 - \lambda_H/\rho_2^G}{1 - \lambda_H}. \tag{5.22}$$

Finally, at $t = 1$ we have the following bank objective:

$$\max_{s_1} \quad V_1^G = s_1 p B^L + (1 - s_1) p B_1^{NL,G} + p V_2^G,$$

where it has to be noted that the continuation probability now only depends on p. As the bank will always be assisted (either by the CB or by the FA) it will only fail if its investment does not succeed. From this optimization I deduce the new critical value for the CB's initial reputation:

$$\rho_1^G(q_1^G) = 1 - \frac{1}{q_1^G}\left(\frac{rxd}{g\mu(r+k}\right). \tag{5.23}$$

Combining these three equilibrium conditions and comparing them to results of the basic model leads to the following result.

Proposition 5.6: *a government bailout increases the need for reputation building by the CB, so $q_1^G > q_1^*$. It also decreases the range of initial reputation values λ_H for which the bank is liquid at* $t = 1$.

Proof: see appendix. ■

Indeed, the introduction of a government that can bail out the bank above and beyond the CB's efforts will diminish the bank's incentives to be liquid. This means that the CB has to exert more effort to build a reputation (q_1 has to be higher) to make the bank liquid in period 2, while initial reputation has to be higher to make the bank liquid in period 1.

The reason is that the bank now gets an additional chance when the CB does not provide liquidity; previously, it simply failed in this case. Even though this is costly in gross terms the bank's net expected profit increases when there is the possibility to be bailed out by the government. Only when the government appropriates all bank value ($g = 1$, i.e. it nationalizes the bank) will the bank not profit from a government bailout.

As with the case of penalty rates, this result may change when we allow for project selection or monitoring. In that case, the bank may suffer from a government bailout if it chooses a low quality project. In Eijffinger and Nijskens (2011) we provide a more detailed investigation of this case, albeit not in a constructive ambiguity context.

5.6 CONCLUSION

For a central bank with a financial stability mandate, reputation is an important asset. It can facilitate a policy of ambiguous bailouts, which in turn can motivate banks to choose prudent asset allocations when facing liquidity shocks.

In a stylized model of the interaction between a central bank and a bank I demonstrate that reputation and the strength of the financial stability mandate both play an important role. In particular, for reputation building to be possible the financial stability mandate should not be too broad: if a bank knows that its failure costs are very large (eg. because it is Too-Big-to-Fail) the CB cannot build a reputation for toughness. Also, if its initial reputation is already high the CB does not need to build it up. The high reputation will lead to a credible no-bailout policy, in response which the bank is always liquid.

When a CB is able to build a reputation, it will do so by adjusting its expected bailout probability. As in Backus and Driffill (1985), reputation building involves a risk since there is a positive probability that the CB will indeed bail out and blow its reputation; a risk that has to be taken to convince the bank to be liquid in the future.

This equilibrium bailout probability is affected by changes in environmental variables. For instance, if the CB's initial reputation is high, it does not have to take as much risk to build a reputation in the future. This also holds for the probability of the liquidity shock and the bank's capital buffer, which both decrease the bank's opportunity costs of being liquid so the CB has to take less risk to build a reputation. The shock size, however, increases the bank's opportunity costs of liquidity and thus require more reputation building effort from the CB.

I additionally study two possible extensions. When the CB can charge a penalty rate on its liquidity assistance, the bank will be more willing to be liquid and reputation building is easier. The other possibility is that there is a fiscal government that bails out banks who do not receive liquidity from the CB. This means that, de facto, the bank gets another chance after being left to fail by the CB. This will diminish its incentives to be liquid and thus the CB has to exert more effort in reputation building.

There are also some limitations of this analysis: I do not consider the bank's risk shifting incentives explicitly, and the CB's bailout decision is only a binary one. However, comparative statics show that portfolio risk (embodied in the probability of success) has a positive effect on next period's liquidity. To fully analyze risk shifting we should incorporate some private benefits as in i.e. Ratnovski (2009). The binary choice of bailout can be seen as the choice between assistance or nationalization, in which the bank owner loses everything and the bank continues with a new owner. It can be generalized to partial assistance or assistance up to a certain threshold, as in Eijffinger and Nijskens (2011).

Finally, a discussion of implementability is in order. To begin with, reputation building and ambiguity are difficult to sustain during a system-wide financial crisis: central banks and regulators just do not have a choice but save systemically important banks.

This relates to the comment by Jeffrey Lacker, who states that after the recent financial crisis ambiguity is no feasible strategy anymore: it may indeed be very hard to establish such a policy.

However, when dealing with individual bank distress (which occurs more often) ambiguity may be a desirable feature of central bank (LLR) policy. To allow for this, we should redesign the financial stability mandate of central banks. A tractable way of doing this is resorting to less transparency, eg. by not stating explicit goals or actions. Another possibility is to provide more discretion to central banks in executing their mandate by not specifying exactly what its objectives are. Yet, it should be noted that these policy changes will hinder the democratic accountability process; it may prove to be very difficult to satisfy both credibility and accountability demands.

5.A APPENDIX: PROOFS

Proof of Proposition 5.1:

This proof shows that when $\lambda_H = 0$ or $\theta_D > \frac{1-p}{p-1/2}xd$, it is not possible to build a reputation such that $\rho_2 > 0$ in equilibrium.

Let us start by stating the first order conditions (FOC) for both players:

$$\frac{\partial V_2}{\partial s_2} = \mu\rho_2(r+k) - rxd = 0 \tag{5.A.1}$$

$$\frac{\partial \Lambda_1}{\partial q_1} = (1-s_1)\left(2(1-p)(xd+\theta_D) - \theta_D - (1-s_2)(1-p)(xd+\theta_D)\right) = 0. \tag{5.A.2}$$

As follows from Bayes' rule in equation (5.7), $\rho_2 = 0$ if $\lambda_H = 0$. If $\rho_2 = 0$, the bank chooses $s_2 = 0$ as follows from its first order condition (5.A.1): this cannot hold for $\rho_2 = 0$. Indeed, it is negative. The CB's FOC will also be negative if $s_2 = 0$, which means it chooses $q_1 = 0$ (this minimizes its loss).

For $\theta_D > \frac{1-p}{p-1/2}xd$, the CB's FOC is negative for all s_2. Therefore, the CB will always choose $q_1 = 1$ as this minimizes its loss. This in turn will reduce its reputation ρ_2 to zero, which causes the bank to choose $s_2 = 0$ as above. As these are both best responses we have an equilibrium in which the CB chooses $q_1 = 1$ and the bank chooses $s_2 = 0$ when $\rho_2 = 0$.

Proof of Proposition 5.2:

The condition for the bank to choose $s_2 = 1$ is $\rho_2 > \frac{rxd}{\mu(r+k)} \equiv \rho_2^*$. This requires

$$q_1^* > \frac{1 - \frac{\lambda_H}{\rho_2^*}}{1-\lambda_H}, \tag{5.A.3}$$

which holds for $q_1 = 0$ as $\lambda_H > \rho_2^*$ and thus the RHS of (5.A.3) is negative.

This equilibrium choice is also a best response for the CB, as its FOC at $s_2^* = 1$ boils down to

$$\theta_D < \frac{1-p}{p-1/2}xd, \tag{5.A.4}$$

which holds since we have assumed $\theta_D < \overline{\theta}_D$. As $q_1^* = 0$, $s_1^* = 1$ too since $\rho_1^*(q_1^*)|_{q_1^* \to 0} = 0$ in equation (5.11).

Proof of Lemma 5.1:

Equation (5.11) in the text shows that $s_1 = 1$ for $\rho_1 > \rho_1^*(q_1^*)$. What is left is determining q_1^* to obtain a threshold ρ_1^* that depends only on parameters.
As $\theta \in (\underline{\theta}_D, \overline{\theta}_D)$ we know that $q_1 \in (0,1)$. Also, since $\rho_1 \in (0, \rho_2^*)$, we know that reputation building leads to $s_2 \in (0,1)$. These q_1 and s_2 are uniquely determined in equilibrium by the model parameters through the CB's first period FOC (equation (5.10)), the banks second period FOC (equation (5.12) and Bayes' rule (equation (5.7)), so

$$q_1^* = \frac{1 - \frac{\lambda_H}{\rho_2^*}}{1 - \lambda_H}. \tag{5.A.5}$$

If we insert equation (5.A.5) into $\rho_1 > \rho_1^*(q_1^*)$ we get:

$$\rho_1 > 1 - \frac{1-\rho_1}{1 - \frac{\rho_1}{\rho_2^*}}(1 - Y), \tag{5.A.6}$$

where $Y = \frac{rxd}{\mu(r+k+V_2)}$. Rearranging this leads to:

$$\rho_1 > \overline{\rho}_1^* \equiv Y\rho_2^*. \tag{5.A.7}$$

Proof of Proposition 5.5:

The need for CB reputation building follows from ρ_2^P. To prove that $q_1^P < q_1^*$ I thus first consider ρ_2^P and ρ_2^*:

$$\rho_2^P = \frac{rxd - \mu(r_P xd)}{\mu(r + k - r_P xd)}, \tag{5.A.8}$$

which is equal to ρ_2^* for $r_P = 0$. We then use

$$\frac{d\rho_2^P}{dr_P}|_{r_P=0} = \frac{xd(rxd - \mu(r+k))}{\mu(r+k)^2} < 0 \tag{5.A.9}$$

to establish that $\rho_2^P < \rho_2^*$. As $q_1^P = \frac{1-\frac{\lambda_H}{\rho_2^P}}{1-\lambda_H}$ this means that $q_1^P < q_1^*$.

At $t = 1$ the bank chooses $s_1^P = 1$ for $\lambda_H > 1 + \frac{1}{q_1^P}(\frac{rxd-\mu(r+k+V_2^P)}{\mu(r+k+V_2-r_P xd)})$. Replace q_1^P:

$$\lambda_H > \overline{\rho}_1^P \equiv \rho_2^P Y^P, \tag{5.A.10}$$

where $Y^P = 1 - \frac{\mu(r+k+V_2^P)-rxd}{\mu(r+k+V_2^P-r_P xd)}$. Note that $\overline{\rho}_1^P$ reduces to $\overline{\rho}_1^*$ for $r_P = 0$. To establish the relative sizes of ρ_1^P and ρ_1^* we then employ

$$\frac{d\overline{\rho}_1^P}{dr_P}|_{r_P=0} = \left(\frac{d\rho_2^P}{dr_P}Y^P + \rho_2^P\frac{dY^P}{dr_P}\right)|_{r_P=0}. \tag{5.A.11}$$

We already know that $\frac{d\rho_2^P}{dr_P}|_{r_P=0} < 0$, and that $Y^P|_{r_P=0} > 0$ and $\rho_2^P|_{r_P=0} > 0$. Investigating the expression for Y^P, in which r_P appears only once, reveals that $\rho_2^P\frac{dY^P}{dr_P} < 0$ for all r_P. The conclusion from this exercise is that $\frac{d\overline{\rho}_1^P}{dr_P}|_{r_P=0} < 0$ and thus $\overline{\rho}_1^P < \overline{\rho}_1^*$, which means the bank is liquid in period $t = 1$ for a larger range of initial reputation λ_H.

What remains is determining the probability of being liquid at $t = 2$. Using

$$s_2^P = \frac{\frac{p}{1-p}\theta_D - xd(1-r_P)}{\theta_D + xd(1-r_P)} \tag{5.A.12}$$

I again employ comparative statics at $r_P = 0$:

$$\frac{ds_2^P}{dr_P}|_{r_P=0} = \frac{\theta_D xd}{(1-p)(xd+\theta_D)^2} > 0, \tag{5.A.13}$$

so $s_2^P > s_2^*$ and the penalty rate makes the bank liquid more often in period 2.

Proof of Proposition 5.6:

As in the proof above, the need for CB reputation building follows from ρ_2^G. From equation (5.21) in the text I deduce that $\rho_2^G > \rho_2^*$ for $g < 1$. Using that

$$q_1^G = \frac{1 - \frac{\lambda_H}{\rho_2^G}}{1-\lambda_H} \tag{5.A.14}$$

and noting that $\rho_2^G > \rho_2^*$, it follows that $q_1^G > q_1^*$. The threshold $\overline{\rho}_1^G$ is determined by combining equation (5.A.14) and

$$\rho_1^G > \overline{\rho}_1^G(q_1^G) = 1 - \frac{1}{q_1^G}(\frac{rxd}{g\mu(r+k}), \tag{5.A.15}$$

and simplifying these to

$$\rho_1 > \overline{\rho}_1^G \equiv \rho_2^G Y^G, \tag{5.A.16}$$

where $Y^G = \frac{rxd}{g\mu(r+k)}$.
Note that $\overline{\rho}_1^G$ reduces to $\overline{\rho}_1^*$ for $g = 1$. To determine the relative size of $\overline{\rho}_1^G$ and $\overline{\rho}_1^G$ we need only establish the relative size of Y and Y^G, as $\rho_2^G > \rho_2^*$ is proven above. Consider

$$Y^G = \frac{rxd}{g\mu(r+k)} > \frac{rxd}{\mu(r+k+V_2)} = Y, \tag{5.A.17}$$

which holds for $g < \frac{r+k+V_2(s_2)}{r+k}$ and where $V_2(s_2) = p(r+k-rxd) > 0$ for $s_2 \in (0,1)$. Since $g < 1$ and $\frac{r+k+V_2(s_2)}{r+k} > 1$, it follows that $Y^G > Y$ indeed holds for all values of g in the relevant interval. Therefore, $\overline{\rho}_1^G > \overline{\rho}_1^*$ for $g < 1$ and the range of λ_H for which the bank is liquid at $t = 1$ is diminished.

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